LECTURES

ON

ASTRONOMY.

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LECTURES

ON

ASTRONOMY;

ILLUSTRATED BY THE

ASTRONOMICON,

OR

A SERIES OF MOVEABLE DIAGRAMS,

FORMING AN ELEGANT SUBSTITUTE FOR THE ORRERY:

WITH

AN APPENDIX,

CONTAINING

ONE THOUSAND QUESTIONS AND EXERCISES

ADAPTED TO THE LECTURES;

AND A NUMBER OF VALUABLE PROBLEMS ON THE ASTRONOMICON.

BY W. H. PRIOR.

Whatever hopes for the veneration of mankind must have invention in the design or the execution; either the effect must itself be new, or the means by which it is produced. Either truths hitherto unknown must be discovered, or those which are already known, enforced by stronger evidence, facilitated by clearer method, or elucidated by brighter illustrations. RAMBLER.

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TO

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PRESIDENT OF THE LONDON MECHANICS' INSTITUTION,
OF THE METEOROLOGICAL AND CHEMICAL SOCIETIES,
AND OF THE MEDICAL AND CHIRURGICAL SOCIETY OF LONDON,
HONORARY MEMBER OF THE LITERARY AND
PHILOSOPHICAL SOCIETIES OF BRISTOL AND LEEDS,
&c. &c.

THIS WORK,

IN TESTIMONY

OF GRATITUDE FOR HIS CONDESCENDING KINDNESS,

OF RESPECT FOR HIS HIGH ATTAINMENTS,

AND

OF REGARD FOR HIS GREAT WORTH,

IS,

WITH PERMISSION,

MOST RESPECTFULLY DEDICATED,

BY HIS MOST OBEDIENT

AND MUCH OBLIGED

HUMBLE SERVANT,

W. H. PRIOR.

PREFACE.

To expatiate on the importance of Astronomy, both as an useful and ornamental science, must at this time be wholly unnecessary, its merits in both points of view, being now too justly appreciated and too generally acknowledged, to require any new proof or illustration.

Whilst, however, the interest and utility of this science are universally admitted, it is observable that the knowledge of it is far from being so extensively diffused as might reasonably be expected and desired; and though it is at the present day considered as forming an indispensable part of a liberal education; — though, too, there are few respectable seminaries for young persons of either sex, in which geography and what is

called the use of the globes are not professedly taught, yet the attainments of the pupils in Astronomical Science are commonly very imperfect and limited.

Now the *real* use of the Globes is to illustrate in a clear and familiar manner the leading principles of Geography and Astronomy; and to exhibit the intimate connection of these two sister sciences; it is therefore obvious, that though the problems on both Globes may be easily performed by arbitrary rules, they cannot be thoroughly understood without a considerable acquaintance with both those sciences, and especially with Astronomy, upon which most of the problems are founded.

In most schools some work on Geography is usually read by those Pupils who are learning the use of the Globes, while, for want of a treatise on Astronomy, properly adapted to the capacities of youth and the purposes of education, this valuable and sublime science, is (more particularly in ladies' schools) almost totally neglected, and the problems being in these cases worked without their application being sufficiently explained by the teacher to be rendered intelligible to the

learner, are commonly forgotten as soon as the exercise is concluded. To provide a remedy for this evil, by supplying what has long been a desideratum in the stock of our school literature, is the chief design of these Lectures.

In the execution of this design, I have endeavoured, by a methodical arrangement of its different parts, to render a science frequently considered too abtruse for the common reader accessible to the most ordinary capacity, to stimulate and interest curiosity by the novelty and beauty of the accompanying illustrations, and by adorning the path of science to allure the youthful mind to its pursuit; in short, to produce a work, which, uniting pleasure with instruction, may invite application by its facility, and reward diligence by its usefulness.

It being one chief object of these Lectures to bring the pupil acquainted with the fixed stars, the knowledge of which forms the basis of all astronomical observations, I have treated the astro-graphical part of my subject much more diffusely than is usual in works of this kind, and have illustrated it by correct views of the

northern and southern celestial hemispheres. I have also added a planisphere on a large scale, and peculiar in its construction, of all the constellations and principal stars visible in our latitudes.

The difficulty commonly experienced in acquiring a knowledge of the starry hosts by means of the celestial Globe, has led me to introduce a number of useful Problems, including all the most important that are usually performed by that instrument. These Problems are worked with extreme facility, especially those which are adapted to the moveable planisphere, and are, together with the Questions and Exercises, thrown into an Appendix which, from its contents, forms a very valuable and interesting portion of this work.

The moveable diagrams afford a more pleasing, familiar, and natural elucidation of the phenomena they are intended to illustrate than any other contrivance hitherto known. They are so constructed as to act upon one common centre, which screws into the middle of a board, upon which all the other figures referred to in the Lectures are also delineated; and by this arrangement, a complete astronomical ma-

chine is formed, which I have designated the ASTRONOMICON.

I now commit my labours to the candid judgment of a discriminating public, trusting that they will answer their professed design, by facilitating to the rising generation the ascent to the Temple of Science.

Crawford Street,
Bryanstone Square.

ERRATA.

Page 2. Note 2. line 3. for *lead* read *head*.
13. line 27. and page 20. lines 3. and 35. for *inclined* read *declined*.
36. line 20. and page 37. line 10. for *Brenchini* read *Bianchini*.
63. line 14. for *western* read *eastern*.
109. last word, for *lessen* read *lessens*.
111. last line but two, for *circlet* read *circle*.
125. line 9. for *six* read *seven*.
136. line 25. for *D* read *C*.
144. line 24. for *ensuing* read *present*.
158. line 129. for *a* read *A*.
181. line 15. for *circle* read *semi-circle*.
190. line 31. for *C D* read *C A*.
194. line 3. after *sun's horizontal* read *parallax*.
204. line 11. for *vary* read *varies*; line 21, for *are* read *is*, and line 25. for *oblute* read *oblate*.
242. last line but two, the comma to come after *so*, instead of after *uniformly*.
300. line 21. for *C* read *E*.
381. line 25. for *orbit* read *orbits*.

DESCRIPTION

OF THE

MOVEABLE DIAGRAMS, &c.

DIAGRAM I.

THE PLANETARY SYSTEM.

This Diagram consists of seven pieces, marked A, B, C, D, E, F, G, which, when placed one upon another in the centre, according to the order of the letters, and unfolded to their full extent, exhibit a representation of the Planetary System, on a scale sufficiently large to convey a very just idea of the relative distances of the Planets from each other, and from the centre of the system. The magnitudes of the Planets, as delineated in this scheme, are also in proportion to one another, and to a supposed globe of two feet diameter for the Sun. The Satellites are merely represented near their respective primaries in order to complete the Diagram, without any regard to their relative distances from those bodies, or to their magnitudes relatively to them.

DIAGRAM II.

THE DIURNAL MOTION OF THE EARTH.

The rotation of the Earth on its axis, causing an apparent diurnal revolution of the Sun about the Earth,

with the nature, extent, and duration of twilight, is represented by this Diagram in a very pleasing and natural manner, while its use in illustrating the cause of the loss or gain of a natural day, experienced by any person in circumnavigating the Globe, as explained in the eighth Lecture, renders it particularly interesting.

DIAGRAM III.

THE EARTH'S DIURNAL REVOLUTION.

The variation in the length of the days and nights throughout the year, is exhibited in this Diagram in a manner peculiarly calculated to make a lasting impression on the mind of the young student, and, together with the corresponding change in the apparent place of the Sun, so obviously pointed out by the index, enables him to obtain more correct ideas respecting the phenomena of the seasons, than the desultory perusal of a whole volume upon the subject would furnish him with.

DIAGRAM IV.

THE MOTION OF THE EARTH IN AN ELLIPTIC ORBIT.

This attempt to exhibit elliptic motion is altogether new; novelty, however, it is presumed, is not its only recommendation. In this as well as the last Diagram, not only the motion of the Earth, but the apparent motion of the Sun produced by it, is particularly illustrated.

DIAGRAM V.

SOLAR AND SIDEREAL TIME.

The difference between Solar and Sidereal Time, or between the length of a Solar and a Sidereal day, and consequently between the number of Solar days in a year, and the number of actual rotations of the

Earth upon its axis during that time, are illustrated by this Diagram with a degree of precision hitherto unattempted.

DIAGRAM VI.

THE APPARENT MOTIONS OF THE INFERIOR PLANETS.

The erroneous illustration of these phenomena given in Ferguson's Astronomy, and in most other Treatises on the same subject, is here fully obviated. To show the angular distance of a Planet from the Sun on an arc considerably beyond the ecliptic, at the same time that we assume the ecliptic as bounding our view in that direction, is, to say the least, unnatural, and presents a difficulty to the student that he cannot easily surmount: nor has the author of this work met with a popular illustration of this subject, which he could consider by any means satisfactory. He has, therefore, in this Diagram given an entirely new illustration of it, which he is happy to say, has received the unqualified approbation of several eminent Professors.

DIAGRAM VII.

THE APPARENT MOTIONS OF A SUPERIOR PLANET.

This Diagram has also been highly approved of, as affording a more clear and natural elucidation of this very abstruse subject than has yet appeared.

DIAGRAM VIII.

THE PHASES OF THE MOON.

This Diagram needs no explanation, its design being obvious on inspection.

DIAGRAM IX.

SOLAR AND LUNAR ECLIPSES.

The plane of the ecliptic is in this Diagram raised, in order to give room for inclining the plane of the Moon's orbit, by which arrangement, and by preserving the parallelism of that plane to itself while it is carried round the ecliptic, the dependance of solar and lunar eclipses upon the position of the Moon in her orbit, relatively to the Sun and Earth at the time of the Moon being new and full, is clearly demonstrated.

THE MOVEABLE PLANISPHERE.

Upon this Planisphere, from the peculiarity of its construction, the most important Problems usually performed by the celestial Globe, may be worked with much greater facility than by that instrument.

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LECTURES

ON

ASTRONOMY.

LECTURE I.

OF ASTRONOMY IN GENERAL. — DIVISION OF THE SUBJECT INTO THREE HEADS. — GENERAL VIEW OF THE PLANETARY SYSTEM; WITH AN EXPLANATION OF SEVERAL CIRCUMSTANCES COMMON TO ALL THE PLANETARY BODIES.

ASTRONOMY[1] is that science which treats of the nature and motions of the heavenly bodies; explains the various phenomena[2] which these bodies exhibit, and demonstrates the laws by which their motions are governed and regulated.

Of the heavenly bodies some appear to be in continual motion among themselves, and to be perpetually changing their places in the sphere[3] of the heavens; while others constantly retain the same invariable position with respect to each other, and seem to be in a state of absolute quiescence. These last, from their appearing to occupy that

[1] From ἀστρον a star, and νομος a law.
[2] Plural of phenomenon; from φαινομαι to appear.
[3] From σφαῖρα a sphere or globe.

situation in the universe in which they were originally placed, are denominated the Fixed Stars.

Those bodies which seem to have a proper motion of their own, and to perform a complete revolution in the heavens in different periods, and in the various paths assigned them, are the Sun, the Planets [1], and the Comets [2]; which, together, constitute what is called the Solar [3] System.

The Comets, however, being distinguished from the Planets by their dull and cloudy appearance, a long train of light by which they are accompanied, their moving in every possible direction, and by their being found in every part of the firmament, may be considered as a distinct species of bodies.

In treating, therefore, this most sublime and interesting science, the above considerations will naturally suggest a division of the subject into three distinct heads, which may be called The System of the Sun and Planets, The System of the Comets, and The System of the Fixed Stars.

The Planetary System,

consists of the Sun ☉, and Planets; the latter being subdivided into three kinds; viz. The Primary Planets; The Minor Primary Planets, or Asteroids [4], and the Secondary Planets, commonly called Satellites [5], or Moons.

1 From *πλανητης* wandering.

2 From *coma* hair. The train of light which accompanies a comet has, in certain situations, an appearance of hair surrounding the nucleus or lead of the phenomenon, which is thence called a comet, or hairy star.

3 From *sol* the sun.

4 From *αστηρ* a star, and *ειδος* a form.

5 From *satelles* an attendant or guard.

The Primary Planets are those which revolve round the Sun as a centre: they are seven in number: their order in the system, and the names and characters by which they are expressed being as follows: Mercury ☿, Venus ♀, Earth ⊖, Mars ♂, Jupiter ♃, Saturn ♄, and Uranus ♅, called also the Georgium Sidus[1], or Herschell.

The Minor Primary Planets, or Asteroids, are four in number: they revolve round the Sun as a centre, between the orbits[2] of Mars and Jupiter, but are distinguished from the Primary Planets by their diminutive size, and by the form and position of their orbits. Their names and characters are Vesta ⚶, Juno ⚵, Ceres ⚳, and Pallas ⚴.

Superior and inferior, or exterior and interior, are relative terms applied to the Primary and Minor Primary Planets: those being called superior or exterior, which are farther from the Sun; and those inferior or interior, which are nearer to him: thus, in respect of our Earth, Mercury and Venus are inferior planets, and the rest are superior. Mercury being the nearest planet to the Sun, and Uranus the most remote from him, may be considered, the former as the inferior planet of the system, and the latter the superior.

The Satellites, or Secondary Planets, are those bodies which revolve round their respective primaries as their centre of motion, in the same manner as the primary planets circulate round the Sun. The number of satellites, at present known, is eighteen; viz. the Moon ☽, which attends on our Earth, four belonging to Jupiter, seven to Saturn, and six to Uranus.

1 From *sidus* a star.

2 From *orbita* a track. The imaginary track or path, in which a primary planet revolves round the Sun, or a secondary planet round its primary, is called its orbit.

The planetary system, therefore, is composed of thirty bodies, viz. the Sun, seven Primary Planets, four Minor Primary Planets, and eighteen Secondary Planets.

In the description hereafter to be given of these bodies, various terms will be employed, which, although they may perhaps be generally, may, nevertheless, not be universally, understood. It will be proper, therefore, in order to avoid ambiguity, that these terms should first of all be explained; to do which with the greater effect, I shall, in this place, mention several circumstances that are common to all the planets in the system, whether Primary, Minor Primary, or Secondary.

The orbit in which a planet revolves round the Sun, or a satellite round its primary, is not of a circular but of an elliptical form, and the Sun, instead of being placed in the centre, is situated in one of the foci[1] of the ellipse.

Without referring to its generation from the section of a cone, an ellipse may be thus described. Let a thread, having the two ends tied together, be put over a couple of pins fixed upright upon a plane, at any distance apart less than the length of the thread, thus doubled, will reach; then a pen or pencil, carried round [illegible] the thread, and keeping it stretched out to its utmost extent, will describe upon the plane an ellipse, which will be more or less elliptical, in proportion to the greater or less distance of the pins from each ot[illegible]. The points in which the pins were fixed are called the foci of the ellipse, and have this particular property, that if two right lines be drawn from them to any part of the circumference, the [illegible] these two lines is equal to the

[1] Plural of *focus* a fire-hearth.

longer axis of the ellipse, or that in which these points are situated.

Let the ellipse, APDE, fig. 1, represent the orbit of a planet. The Sun is not placed at C, the centre of the orbit, but at S, one of the foci of the ellipse. When the planet therefore is at P, it is in that part of its orbit which is nearest the Sun, and is said to be in perihelion.[1] In performing its revolution round the Sun, its distance from that luminary gradually increases till it reaches the opposite point of its orbit, when it is at its greatest distance from the Sun, and is said to be in its aphelion.[2] When it arrives at the points D and E of its orbit, it is said to be at its mean distance. The points A and P of the orbit, the one of which is farthest from, and the other nearest to, the Sun, are called the apsides[3], the former of which is called the higher, and the latter the lower apsis, and the line AP, which joins these points is called the line of the apsides, and also the greater or transverse axis; DE is the lesser or conjugate axis; S the lower focus, or that in which the Sun is placed, and *s* the higher focus. SC, or *s* C, the eccentricity[4] of the orbit, and SD, or SE, the mean distance.

The mean distance added to the eccentricity is equal to the aphelion distance, SA; and the mean distance less the eccentricity is equal to the perihelion distance, SP; consequently the difference between the aphelion and perihelion or greatest and least distance of a planet from the Sun, is

[1] From περι about, near, and ἥλιος the sun.

[2] From απο from, and ηλιος.

[3] Plural of *apsis*, from αψις a bend like a wheel, because the planet, at these points, appears to bend or turn back.

[4] From ἐκ out of, and κεντρον centre.

equal to double the eccentricity of the orbit of that planet.

A planet does not proceed with an equable motion through every part of its orbit; the velocity of its motion gradually increasing while the planet is moving from its aphelion to its perihelion, and as gradually decreasing while it is going from its perihelion to its aphelion. The anomaly [1] of a planet is its distance from the aphelion, and is considered as either true or mean. The true anomaly of a planet is its angular distance at any time from its aphelion. The mean anomaly is the angular distance of a planet from its aphelion, upon the supposition that it moves uniformly in a circular orbit. The equation of the planet's centre is the difference between the true and mean anomaly.

When the Sun or Moon is nearest to the Earth, it is said to be in perigee. [2] The Sun or Moon is said to be in apogee [3] when it is most distant from the Earth. Thus, if fig. 1. represents the orbit of the earth, then when the Earth is at P, or in perihelion, the Sun is said to be in perigee; and when the Earth is at A, or in aphelion, the Sun is said to be in apogee.

The line of the apsides of the several planets lie in different directions, and consequently point to different parts of the heavens. The orbits of some of the planets are more elliptical than others, and most of them are very nearly circular. Having mentioned the elliptical form of an orbit as a general property belonging to the orbits of all the planets and satellites in the system, and explained several terms arising

1 From α not, and νόμος law.
2 From περὶ about, and γῆ the earth.
3 From ἀπὸ from, and γῆ.

from it, I shall defer making any further observations upon this subject till the apparent motions of the Sun come to be investigated, when this phenomenon will be fully described and accounted for.

If we suppose a plane to pass through the Earth's orbit and to be extended in all directions to the sphere of the heavens, it will trace out a line among the stars which is called the Ecliptic [1], because eclipses can only happen (as will be shown when these phenomena come to be treated of) when the Moon is either in, or very near to, that line. In like manner we may imagine planes to pass through the orbits of the other planets, and to be extended to the sphere of the Fixed Stars, describing circles thereon coincident with the orbits of the several planets. The circles thus generated, being evidently the circles which the several planets would appear to describe to a spectator placed in the centre of the Sun, are called the Heliocentric [2] Circles of the planets; the ecliptic is, therefore, the earth's heliocentric circle. Now it is evident that if the planets moved in the plane of the ecliptic they would constantly appear in that circle, which would then become the heliocentric circle of all the planets. This is not, however, the case. Repeated observations demonstrate that they are sometimes above and sometimes below the ecliptic, upon which they are only seen twice during the whole course of their several revolutions round the Sun; and since the heliocentric circle of a planet must necessarily coincide with the plane of that planet's orbit, by finding the heliocentric circle of any planet in the sphere of the heavens, the situ-

[1] The word eclipse, from which this circle takes its name, is from εκλειπω to leave, to faint.

[2] From ηλιος the sun, and κεντρον the centre.

ation of the plane of its orbit is known. The heliocentric circles of all the planets being found to be different, it was ascertained that the orbits of the planets are inclined at different angles to the ecliptic, and that the orbit of each planet crosses that circle in two opposite points, which points are called the Nodes[1] of the planet; that node from which any planet ascends above the ecliptic being denominated its ascending, and that from which it descends below the ecliptic its descending node: the line which joins these points is called the line of the nodes. Since the times in which the several planets appear to describe their heliocentric circles, are the same as the periods in which their real revolutions are performed, the difference between the former of these must be the same as the difference between the latter.

To an inhabitant of any planet, the Sun appears to perform a complete revolution of the heavens in the heliocentric circle, and in the periodical time of that planet; the apparent motion of the Sun being in the same direction in which the planet moves. By the motion of the Earth, therefore, in its orbit, the Sun appears to perform an annual revolution in the ecliptic, and always to be in the opposite part of the heavens to that in which the Earth is situated; hence the ecliptic is frequently called the *Via Solis*, or Sun's Path.

The ecliptic is divided into twelve equal parts, called signs, which are named after certain constellations[2] in the heavens through which the ecliptic itself passes; and a space extending about eight degrees on each side of the ecliptic is called

1 From *nodus* a knot.
2 From *con* for *cum* with, and *stella* a star.

the Zodiac [1], because the constellations through which the ecliptic passes consisted, according to the Chaldean division, entirely of animal figures, the constellation now called Libra having originally formed the claws of the Scorpion. Hence Libra is still sometimes called *Chelæ* (the claws).

The names, order, and characters of the twelve signs into which the Zodiac is divided, are, Aries ♈, the Ram; Taurus ♉, the Bull; Gemini ♊, the Twins; Cancer ♋, the Crab; Leo ♌, the Lion; Virgo ♍, the Virgin; Libra ♎, the Balances; Scorpio ♏, the Scorpion; Sagittarius ♐, the Archer; Capricornus ♑, the Goat: Aquarius ♒, the Water-Pourer; and Pisces ♓, the Fishes.

The characters made use of to represent the signs of the Zodiac are generally supposed to be of very ancient invention, and were doubtless designed as rough representations of the figures they are intended to signify; thus ♈ represents the horns of the Ram; ♉ the head and horns of the Bull: ♊ the Twins joining hands and feet; ♋ is supposed to represent the change of the Sun's declination from north to south, which takes place in this sign; ♌ represents the tail of the Lion; ♍ was originally the three ears of corn, which are generally drawn in the hand of the Virgin; ♎ is the beam of the Balance; ♏ is a barbarous transcript of the original character, which was a rude picture of the Scorpion; ♐ is the arrow of the Archer; ♑ is a deviation from the original character ♑, which is intended for a rough but expeditious representation of the figure of the constellation; ♒ is a natural imitation of the undulating

[1] From ζωδιον an animal.

surface of water; and ♓ is the picture of two fishes tied back to back.

Although the signs of the Zodiac are equal in extent, containing each thirty degrees, yet the constellations from which their names are derived are unequal, some extending much farther than others, as may be seen by inspecting a common celestial globe; hence the Zodiac is by some authors considered as astral or local; the former being the Zodiac divided into twelve unequal parts by the twelve constellations, and the latter the Zodiac divided into twelve equal parts or signs, each of which is sub-divided into thirty equal parts called degrees, each degree into sixty equal parts called minutes, and each minute into sixty equal parts called seconds.

Hipparchus first introduced this fixed Zodiac (as it is called) among the Greeks, about 2000 years ago, and placed Aries as the first of the signs, whereby, in his time, the signs corresponded with the constellations after which they were named. By the precession of the equinoxes (hereafter to be explained) these signs have retrograded, or moved backwards, or contrary to the order of the signs, about 30 degrees since the time of Hipparchus, by whom this retrograde motion was discovered; they, however, still retain their ancient names, notwithstanding their having shifted their places with regard to the constellations one whole sign; thus the first sign, or first of the twelve equal portions into which the ecliptic is divided, is still called Aries, although it now corresponds with the constellation of the Fishes, the second sign is called Taurus, though in the constellation Aries, and so on.

The Egyptians and Chaldeans had reckoned according to the fixed Zodiac ages before the time of

Hipparchus, and it was probably known to astronomers from a very early period. Unless otherwise expressed, the fixed or intellectual Zodiac of Hipparchus is always to be understood when the Zodiac is spoken of. As the signs of the ecliptic, or fixed Zodiac, have no corresponding stars, they are sometimes called anastrous [1] signs, to distinguish them from the astral Zodiac, or signs formed by the stars.

The various inclinations of the orbits of the planets to the ecliptic are in round numbers as follows: The inclination of Mercury's orbit is about 7°; that of Venus about $3\frac{1}{2}$°; of Mars about $1\frac{5}{6}$°; of Jupiter about $1\frac{1}{4}$°; of Saturn about $2\frac{1}{2}$°; and of Uranus about $\frac{2}{3}$ of a degree. The heliocentric circles of the primary planets are all, therefore, comprehended within the limits of the Zodiac: but those of the minor primary planets, Vesta's excepted, exceed those limits, being considerably more inclined to the orbit of the earth; thus the inclination of the orbit of Vesta is about $7\frac{1}{7}$°; of Juno 13°; of Ceres $10\frac{1}{2}$°; and of Pallas $34\frac{1}{2}$°.

While the primary planets are revolving round the Sun, and the satellites round their respective primaries, these various bodies have at the same a motion from west to east round their axes, by which, to a spectator placed upon any of them, the whole heavens, with all the visible bodies contained therein, will appear to revolve round the planet on which he stands during the time that the planet itself takes to turn upon its axis, but in a direction exactly the reverse of that in which its rotation is performed. That of the Earth being performed in twenty-four hours, the heavens will appear to

[1] From α not, and αστρον a star.

make a complete revolution from east to west in that time.

All that is meant by the axis of a planet, or other heavenly body, is that imaginary line round which its revolutions are performed, and not that it has any material axis to turn upon. The axes of the different planets are variously inclined to the ecliptic and to their own orbits: a line perpendicular to the axis, and dividing a planet into two equal parts, is called its equator. If N S, fig. 2., represent the axis upon which the Earth, NQSÆ, revolves, the point N is called the north, and S the south pole; the line ÆQ, perpendicular to the axis, and dividing the Earth into two equal parts, is called the Equator; the half, ÆNQ, being denominated the northern, and the other half, ÆSQ, the southern hemisphere. EE is the ecliptic; and the angle ECÆ, or ECQ, the Obliquity of the Ecliptic to the equator; NCE the inclination of the Earth's axis to the ecliptic; the opposite points at C, (one of which only is visible in the figure,) where the equator intersects the ecliptic, are called the equinoctial [1] points, and the line joining these points the line of the equinoxes.

The ecliptic has already been mentioned as the track marked out among the stars by extending the plane which passes through the orbit of the Earth; this circle, therefore, evidently divides the heavens into two vast concave hemispheres [2], that being denominated the northern hemisphere to which the north pole of the Earth is directed, and that the southern to which its south pole inclines.

[1] From *æquus* equal, and *nox* night, so called, because when the Sun is in either of these points the days and nights are of an equal length at all parts of the earth.

[2] From *ημισυ* half, and *σφαιρα* a sphere.

The distance of any heavenly body from the ecliptic, measured on a great circle perpendicular to it, and passing through that body, is called the latitude of the body, and is north or south as it is in the northern or southern hemisphere. The ecliptic being a common boundary of both these hemispheres, it is evident that any star, planet, or other body, situated in this line, can be, properly speaking, neither in the one hemisphere nor the other, and, consequently, can have no latitude.

Now if the Earth's axis were perpendicular to the plane of the ecliptic, it is clear that the poles of the ecliptic would coincide with the poles of the world as they are called, or those points in the sphere of the heavens through which the Earth's axis, infinitely extended both ways, would pass; and that the plane of the ecliptic would in like manner coincide with the plane of the Earth's equator, and, consequently, the celestial equator and the ecliptic would be one and he same circle; and, therefore, celestial and terrestrial objects, having the same latitude, would exactly correspond to each other: hence all the stars, having any given latitude in the heavens, would become celestial correspondents to all places having the same latitude on the surface of the Earth. Since, however, the axis of the Earth is inclined from the perpendicular about 23° 28′, equal to the obliquity of the ecliptic to the equator, it follows that the same celestial and terrestrial latitudes do not coincide, being measured from circles that are oblique to each other.

The ecliptic having been chosen by astronomers as the circle upon which the distance of the heavenly bodies was to be measured, it became necessary, in order to ascertain their exact situation, to fix upon some determinate point at which the reckoning was to commence. As the equinoctial

points, or those two opposite points of the heavens in which the Earth's equator extended intersects the ecliptic, must always be situated in the ecliptic, the vernal[1] equinox, or that in which the Sun is placed in spring, was chosen for this purpose. The longitude of a star, planet, &c. is its distance reckoned on the ecliptic in signs, degrees, and minutes, from the vernal equinox, or the first point of Aries. If the star, &c. be not situated in the ecliptic, but somewhere north or south of it, then the point in which the ecliptic is cut by a great circle perpendicular to it, and passing through the star, &c. is called the longitude of that body. If we suppose the line of the apsides of any planet produced both ways till it meet the ecliptic, the distance of the aphelion extremity of this line from the vernal equinox is called the longitude of the aphelion, and the distance of the other extremity the longitude of the perihelion. The longitude of the nodes of any planet is reckoned in a similar manner.

Some few authors, instead of reckoning the longitude of a heavenly body from the first point of Aries, in the fixed Zodiac of Hipparchus, imagine a circle of latitude to be drawn through a star in the head of the Ram, hence called the first star of the Ram, and reckon the longitude in signs, degrees, and minutes, from the point of the ecliptic which is cut by that circle. This star is by Bayer marked γ. The longitude of a phenomenon, thus reckoned, is said to be so many signs, degrees, minutes, &c. from the first star of the Ram. The latitude or longitude of a heavenly body is either geocentric[2], or heliocentric; the former being the

[1] From *vernus* belonging to the spring.
[2] From γῆ the earth, and κεντρον centre.

latitude or longitude of that body as seen from the Earth, and the latter the latitude or longitude it would have if viewed from the centre of the Sun.

If, instead of the ecliptic, the distance of any heavenly body from the vernal equinox be measured on the celestial equator, this distance is called its right ascension. Should the body not lie in the equator, but any where out of it, then, if a great circle be drawn perpendicular to the equator, and passing through the body, the arc of this circle intercepted between the equator and the body itself, is called its declination, and is denominated north, or south, as the body is north or south of the equator, its ascension, being the distance of the point in which this circle cuts the equator from the vernal equinox.

The elements of the planetary orbits are found to be subject to certain variations, which, from being so extremely small, as only to be perceived by comparing observations made at very distant periods, are called secular inequalities. Thus their eccentricity is variable, though their greater axes appear to be always the same, that is, their orbits sometimes approach nearer to true circles, and at others become more elliptical. The inclination of their orbits to the ecliptic, and the position of their nodes, are also subject to small variations. The motions of the planets are likewise subject to other inequalities, which, as they appear to depend on the position of the different planets with respect to each other, are called periodical inequalities: these inequalities are most sensible in the motions of Jupiter and Saturn.

LECTURE II.

PARTICULAR VIEW OF THE BODIES COMPOSING THE PLANETARY SYSTEM COMMENCED.—OF THE SUN.—THE ZODIACAL LIGHT.

FROM the general view of the planetary system contained in the foregoing Lecture, let us proceed to take a more minute survey of the various bodies of which it is composed; and, first, of

The Sun ⊙.

The Sun, and those planets which were known in the early ages of astronomy, had, originally, names given to them, expressive of the peculiar qualities, attributes, or motions of those bodies. Thus ηλιος (*helios*), the common Greek name of the Sun, is derived from the Hebrew *El*, one of the names of God. By the Pheniceans the Sun was called *Baal-shamin*, the Lord of Heaven: both these names were evidently applied to this luminary, as a primary object of idolatrous worship." The Hebrew name *Shemesh*, a minister or servant, is either from his administering light and heat to this lower world, or because he is the immediate servant or agent, employed by the Almighty in dispensing these vivifying principles. The name *Mithra*, signifying love or mercy, by which he was known among the Persians, was given him on account of his cherishing the Earth by his influence; which may be looked upon as

the effect of his love to mankind. Many other names have been given to the Sun by way of epithet, from his light, heat, &c. The Roman name *Sol*, is by Macrobius ascribed to his appearing solus, *i. e.* alone.

The diameter of this immense globe is 883,246 English miles. That this radiant orb, the great source of light, heat, and vegetation, should have been generally considered by the ancients a globe of pure fire, seems by no means surprising. When, however, the invention of the telescope had enabled astronomers, by discovering dark spots of various forms and magnitudes upon its disc [1], to ascertain that this opinion was ill founded, it might perhaps have been hoped, and expected, that future observations would lead to some satisfactory conclusion, respecting the probable construction of this luminary. How far such hopes and expectations (if they ever existed) have hitherto been realised, will be best ascertained, by comparing the theories proposed, with the observations upon which they are founded: for which purpose, I shall here introduce a brief description of the motions and appearances of the solar spots, with the opinions of the most celebrated astronomers concerning them; and shall then proceed to give a general account of the very ingenious theories, of the nature, and construction of the Sun, to which they have given rise.

The solar spots are never stationary, but appear to move slowly over the Sun's disc, from east to west. When a spot first becomes visible on the eastern limb of the Sun, it appears like a thin black line; but as it advances towards the centre of his disc, the breadth of the spot and the velo-

[1] From *discus* a quoit. The face of the Sun, or any planet as it appears to the eye, is called its disc.

city of its motion gradually increase; and they again diminish as it approaches the western limb. These changes in the apparent form and motion of the spot, are merely optical deceptions, arising from its oblique position with regard to the eye of the spectator.

In order to understand this, let us imagine the globe of the sun to have a number of circles drawn upon its surface, all passing through his poles, and intersecting his equator at equal distances. These circles, (which may be called meridians,) if they were visible, would appear to us, on account of the sphericity of the Sun, at unequal distances from each other, and seem to inclose unequal spaces of the Sun's surface, as in fig. 3. Now suppose a spot, of the shape and magnitude represented at *g*; it is evident it would appear of its true form only in the central part of that hemisphere of the Sun which is turned directly towards our earth, that being the only situation in which we could obtain a view of the full extent of it, in length and breadth; in every other position, *a*, *b*, *c*, *d*, *e*, *f*, *h*, *i*, *k*, *l*, *m*, *n*, we have an oblique view of the spot, its breadth being gradually contracted in proportion to its distance from the centre, without any diminution of its length; and at its coming in at *a*, and going off at *n*, it appears merely as a thin black line.

The correspondent inequalities in the motion of the spot, by which it appears to move slower while describing the shorter arcs included between those meridians which are nearer to the eastern and western limbs of the Sun, are also such as prove it to be carried equably round in a circle, the plane of which nearly coincides with the eye of the observer.

Now whatever may be the number of maculæ [1], or faculæ [2], (that is, dark or bright spots,) upon the sun at a time, they all keep in the same situation in respect of one another, and, so long as they last, are carried round together in the same manner; which shows that the spots adhere to the surface of the Sun, or exist in his atmosphere, and revolve along with that body upon his axis; at the same time demonstrating the Sun to be a globular body, and proving it to have such a rotation.

If a spot be observed at different times of the year, it will be found that its path, or the line of its apparent motion over the Sun's surface, is continually varying. At the end of November, and the beginning of December, it seems to move downwards across the Sun's surface in a straight line; about the end of February, and the beginning of March, it describes a curve, having the convexity turned towards the upper part of his disc; after the beginning of March, the curvature decreases till about the latter end of May, or the beginning of June, when it again describes a straight line, but appears to ascend in its passage over the disc of the Sun; and about the end of August, and the beginning of September, it takes the form of a curve, having its concave side turned upwards.

As by the rotation of the Sun on his axis every spot upon his surface is carried round him either in, or parallel to, his equator, the above phenomena, which are repeated every year in the same order, and which belong to all the spots that have been observed on his disc, have enabled as-

[1] From *macula* a spot or stain.
[2] From *facula* a little torch.

tronomers, to ascertain that the axis of the Sun is not perpendicular to the plane of the ecliptic, but inclined from the perpendicular at an angle of about seven degrees and a half. In order to render this clearly understood, let USLN, fig. 4., be the Sun, E *e* the ecliptic, NS the axis round which the Sun revolves, UL a diameter of the Sun perpendicular to the plane of the ecliptic, U his upper, and L his lower limb, A the point at which the spot enters, and *a* the point where it leaves the Sun's disc; when the Earth is at *e*, the circle A *a*, which the spot describes, will appear a curve convex towards U, as in fig. 5., the south polar regions of the Sun at S being visible, because the Earth is below the plane of the circle described by the spot. When the Earth is in the opposite part of its orbit at E, the north polar regions of the Sun at N, will be visible; and as the Earth is above the plane of the circle A *a*, it will be projected into a curve concave towards U, as in fig. 6. When the Earth is half way between E and *e*, as at *c*, where the plane of the circle A *a* intersects the plane of the ecliptic, it will be projected into a straight line, as in fig. 7., and the spot will appear to ascend across the Sun's disc. When the Earth is at *d*, in the opposite part of its orbit to this, it will again come into the plane of the circle, which will therefore be again projected into a straight line, as in fig. 8., the spot appearing to move downwards across the disc of the Sun.

To illustrate the above phenomena, by means of a common celestial or terrestrial globe, put a black spot upon any convenient part of it, and incline the axis about seven degrees and a half from the perpendicular. Then if a spectator move gently round the globe, keeping his eye in

the plane of the horizon, while the globe is made to revolve steadily upon its axis, the variation in the size of the spot, the change of its velocity, and the varieties in the figure of its path, will be pleasingly, and naturally represented.

By carefully observing the time which intervenes between a spot's disappearing on the western limb of the Sun, and its next subsequent disappearance, the period of its apparent revolution will be obtained, which is found to be twenty-seven days, seven hours, and thirty-seven minutes. As the Earth, however, revolves round the Sun in the same direction (as will hereafter be shown), it is evident that the spot must, during this time, have performed something more than a complete revolution, and consequently that the true period of the Sun's rotation on his axis, is something less than the time indicated by the apparent motion of the spot. To understand this, let A B C D, fig. 9, be a section of the Sun parallel to the ecliptic E F G H, when the Earth is at E, the visible hemisphere of the Sun is A B C, A being its eastern, and C its western limb. Let us suppose that when the Earth has just arrived at E, a spot vanishes behind the western limb of the Sun at C; in twenty-seven days, seven hours, thirty-seven minutes, from that time, the spot having been carried round, according to the order of the letters, by the Sun's rotation, will again disappear behind his western limb; but the Earth, during that interval, having advanced in her orbit from E to *e*, the visible disc of the Sun is now B C D, and D its western limb; so that the spot which set out from C, has, during twenty-seven days, seven hours, and thirty-seven minutes, performed one whole revolution, and the part C D, of another. Now the angle D S C, is equal to the angle E S *e*, consequently, the time

in which the Earth has completed one revolution, and the part E e of a revolution, will be to the time in which it completes one revolution, as the time in which the spot has performed one revolution, and the part C D of a revolution, is to the time in which it performs a revolution only, or to the time in which the Sun revolves on his axis. But the time which the Earth has occupied in going through the part E e of a revolution, is 27 days, 7 hours, and 37 minutes, and the time in which it performs a whole revolution, is 365 days, 5 hours, 48 minutes; therefore, 27 days, 7 hours, 37 minutes, + 365 days, 5 hours, 48 minutes = 392 days, 13 hours, 25 minutes, is to 365 days, 5 hours, 48 minutes, as 27 days, 7 hours, 37 minutes, is to a fourth proportional, which will be found to be 25 days, 9 hours, 56 minutes, the time of the Sun's rotation on his axis. The above proportion will be found sufficiently exact for all general purposes, but is not strictly accurate, the arch C D being measured on the ecliptic, instead of the Sun's equator; there is also some inaccuracy arising from the Earth's real motion not being performed equably in a true circle; the error is, however, too trifling to require any farther notice. Without, therefore, dwelling any longer upon the motions of the solar spots, let us proceed to consider the spots themselves, and the solar theories to which they have given rise.

It is the general opinion, that Galileo was the first who discovered the spots on the Sun, in the beginning of the year 1611. Scheiner, however, who was Professor of Mathematics at Ingoldstadt, seems to have made a similar discovery about the same time; which of these observers had the first view of the solar spots, became a matter of controversy between them. Scheiner continued his observ-

ations from 1611 to 1629, during which period he never found the Sun clear of spots, except a few days in December, 1624; at other times, he frequently saw twenty or thirty at a time, and in 1625 upwards of fifty spots were visible at once.

Besides the maculæ, or dark spots, Galileo likewise perceived upon the disc of the Sun faculæ, or luculi [1], which are spots brighter than the rest of his surface, and which move in the same manner as the dark spots. From 1650, to 1670, scarcely any spots were to be seen, and from 1676, to 1684, the Sun appeared totally without spots. Since the beginning of the eighteenth century, scarcely a year has passed in which spots have not been visible, and frequently in great numbers.

The solar spots are, for the most part, of an irregular form, varying both in position and magnitude. They in general consist of a dark space, or nucleus [2], surrounded by an umbra [3], or fainter shade; the boundary between the umbra, and nucleus, being always distinct and well defined: that part of the umbra nearest the dark nucleus, is generally brighter than the more distant portions. It is remarkable, that, however irregular the dark nucleus may be, the outline of the umbra is always curvilinear, without any angles or sharp projections. The spots on the Sun are not permanent; some continue several days, weeks, and even months, together, while others appear and disappear, in the course of a few hours. Hevelius observed one that was lost in sixteen or seventeen hours after its first formation. Those spots that are gradually generated, are mostly as gradually dissolved; whilst those which are suddenly pro-

1 From *lux lucis* light.
2 From *nucleus* a kernel.
3 From *umbra* a shade or shadow.

duced, generally vanish as abruptly. When any spot begins to dilate or contract, the effect takes place on the nucleus, and umbra, at the same time. The nucleus of a spot, while on the decrease, suffers a gradual change of figure, by the umbra encroaching upon it, whereby the boundary between them is perpetually varying; and it frequently happens, that, by the encroachment of the umbra, the nucleus is divided into two or more nuclei. When the spot disappears, the umbra continues visible for a short time after the nucleus has vanished. The umbra is generally succeeded by a facula, or luminous spot; when that is not the case, the place it occupied resembles the other portions of the solar surface. Large umbræ, are seldom seen without a nucleus in their centre, but small umbræ, frequently appear by themselves.

The various conjectures relative to the nature and formation of the solar spots, and of the Sun itself, to which the foregoing very curious facts have given rise, are too numerous to admit of being fully described, and many of them too frivolous to be even mentioned, in a work, the merit of which, is intended to consist less in the investigation of abstruse theories, and unprofitable speculations, than in the solid instruction its pages may contain. Passing by, therefore, a host of opinions, which tend rather to display the folly, or the temerity, of those by whom they were promulgated, than to shed the least ray of light upon the subject they attempt to illustrate, I shall proceed to give a very concise account of those which, from the popularity they have obtained, or the acknowledged celebrity of the persons by whom they were proposed, and the evidence by which they are supported, appear to be best entitled to our consideration.

Scheiner, one of the first observers of the solar spots, did not suppose them to adhere to the Sun, but imagined them to be planets revolving round him, like Mercury and Venus, in orbits not very remote from that luminary.

Others have imagined that they are occasioned by the smoke, and bituminous matter, cast up by the immense volcanoes or burning mountains, with which they suppose the nucleus or body of the Sun to abound; and that as this matter is gradually changed, or consumed, by the luminous fluid surrounding the nucleus, the spots disappear till fresh eruptions take place and produce similar phenomena.

An opinion, which seems to have been more generally received, is, that the Sun is composed of an inflammable fluid matter, in a continual state of ebullition, whereby the scoria, or dross, consisting of the more gross parts, being carried up to the surface of the fluid, swim there for a time, exhibiting all those various appearances which we see in the solar spots; and, at last, being entirely dissipated by the continual rapid motion of the fluid, are consumed thereby, or sink to the bottom and disappear.

Some have thought that the Sun is an opaque body, immersed in a luminous fluid, that it is mountainous, and uneven, like our Earth, and that, by the ebbing and flowing to which they suppose this luminous fluid to be subject (after the manner of our tides), the tops of the solar mountains being sometimes left uncovered, present a black appearance, and form the nucleus of the spot, while the umbra by which the nucleus is generally surrounded has been, by some of the favourers of this hypothesis, ascribed to a kind of foam created by

the obstruction these eminences offer to the action of the fluid, and by others imagined to be those parts of the opaque mass which lie only a little below the surface of the igneous matter.

Dr. Wilson, from observations upon the great spot which appeared in November, 1769, asserts the solar spots to be depressions in, rather than elevations above, the surface of the Sun; and that the black nucleus of every spot, is the opaque body of the Sun seen through an opening in his luminous atmosphere[1], the umbra being the shelvings or sides of these excavations. This theory is deduced from the following facts: When any spot is about to vanish behind the western limb of the Sun, the eastern portion of the umbra first contracts in its width, and then disappears; after which the nucleus gradually contracts and vanishes, while the western portion of the umbra still continues visible. When a spot comes into view on the eastern limb, the eastern portion of the umbra first becomes visible, the dark nucleus is next seen, and, lastly, the western part of the umbra makes its appearance. When two spots are very near to each other the umbra of the one spot is deficient on the side next the other, and if one of the spots be much larger than the other, the umbra of the largest will be completely wanting on the side next the smaller. If the large spot have small ones on each side of it, its umbra, instead of entirely vanishing, appears flattened and compressed toward the nucleus, but expands again as soon as the small spots disappear; from which, Dr. Wilson infers that the western portion of the umbra may disappear before the nucleus, when a small spot happens to be on the western side of it.

[1] From ατμος vapour, and σφαιρα a sphere.

The solar observations of Dr. Herschell, although they have been partially described in most of the modern treatises on astronomy, are too important to be passed over in silence, since the unremitting attention bestowed by him upon this subject during the long period of fifteen years, and the very powerful telescopes made use of by that astronomer, have enabled him to bring to light a number of curious particulars relative to the spots, and to deduce a theory of the solar phenomena, which, if not altogether free from difficulties and objections, seems at least to demand as few concessions as any which has hitherto been proposed for our acceptance.

He considers the lucid matter of the Sun, neither as a liquid substance, nor an elastic fluid, but that it consists of luminous clouds, floating in his atmosphere, and that what has been denominated the nucleus of the spot, is the opaque body of the Sun, viewed through openings in this atmosphere. To those phenomena before known by the names of nuclei, umbræ, faculæ, luculi, &c. he has given the more appropriate and expressive denominations, of openings, shallows, ridges, nodules [1], corrugations [2], indentations, and pores. [3]

Openings are those appearances in which, by the removal of part of the luminous clouds, the opaque body of the Sun becomes visible; they sometimes have a difference of colour, which appears to be caused by a thin veil of luminous clouds hovering over them. Large openings are usually surrounded by shallows, but small ones commonly have none; ridges and nodules also generally accompany open-

1 From *nodulus* a little knot.
2 From *corrugo* to wrinkle.
3 From πορος a passage for perspiration, a spiracle of the skin.

ings. When openings are about to decay they very often divide, and are sometimes converted into large indentations, with or without pores, and not unfrequently into pores. When an opening disappears, the surface becomes unusually disturbed. Openings are supposed, by Dr. Herschell, to be produced by an elastic gas, issuing from the body or nucleus of the Sun, through the minute pores, or smaller openings. By this gaseous stream, the equilibrium of the luminous matter being disturbed, and the clouds, of which he supposes it to consist, being driven out of the way, an aperture is formed, through which the body of the Sun is exposed to view.

Shallows are places whence the luminous clouds of the upper regions are removed, and are therefore depressed below the general level of the solar surface. The depth of the shallows is visible; they generally begin from openings which they surround, and from these surrounding shallows branches frequently proceed, and extend in various directions, sometimes running into each other, at others going forward, or spreading and uniting again with the original shallow. These changes in the form and direction of the shallows are to be attributed to the same cause as originally produced them, viz. the empyreal gas, which, issuing from the opening, drives away the luminous clouds from those parts where it meets the least resistance, or dissolves them by some peculiar agency.

Ridges are accumulations, or elevations, of the luminous clouds rising above the general surface of the Sun; they usually surround openings, although they have been frequently perceived where openings did not exist. They are sometimes of great extent, having been observed 75,000 miles in length, but are seldom of long continuance, gene-

rally dispersing very soon after their first formation.

Nodules, formerly called faculæ, or luculi, are small brilliant and highly elevated parts of the luminous clouds: these being never seen near the middle of the Sun's disc, Dr. Herschell supposes that they may be ridges fore-shortened by their oblique position on the spherical surface with regard to the spectator.

Corrugations consist of small elevations and depressions of the luminous matter, by which they present a mottled appearance of dark and light places: the dark parts appear lower than the bright ones, and are of no regular form, but seem to shoot out in various directions. The corrugations pervade the whole of the Sun's surface, and, under favorable circumstances of atmosphere, are as distinctly perceptible as the rough surface of the Moon: as they are produced by the dispersion of ridges and nodules, it is not wonderful that they undergo a perpetual change of shape, magnitude, and position, and being nothing else than other phenomena in a state of decay, they (as may be expected) increase, diminish, divide, and vanish, very rapidly.

Indentations are the dark parts of corrugations, and, consequently, like them, extend over the whole surface of the Sun; they are evidently of the same nature as shallows, and are probably not much depressed below the general surface of the luminous clouds: they sometimes contain minute openings, and not unfrequently become openings themselves. With a telescope of small power they appear like points.

[illegible] the minute holes or openings already spoken of as occasionally existing in the indenta-

tions; they sometimes increase and become openings, and frequently vanish in a short time.

From the diversified appearance the surface of the Sun presents, the numerous elevations and depressions of the lucid matter, the long continuance of many of the phenomena it exhibits, and the uniformity of colour observable in the shallows, the Doctor concludes that the Sun consists of a dark solid nucleus, surrounded by two strata of clouds; the outermost of which he conceives to be the grand depository of that light and heat which are so copiously diffused through our system, while the interior stratum is intended to protect the inhabitants of the Sun from the destructive effects of the fiery clouds with which they are surrounded. That the dark nucleus, or solid body of the Sun, is a habitable globe, he infers from its similarity to the other bodies of the planetary system with regard to its solidity, its atmosphere, the rotation upon its axis, and the fall of heavy bodies on its surface; analogies so striking, that he considers the Sun (to use his own words) "to be nothing else than a very eminent, large, and lucid planet, evidently the first, or rather the only primary one, of our system, all the rest being truly secondary to it."

The opinion of Dr. Herschell, that the Sun is a habitable globe, is opposed by Dr. Brewster, who, notwithstanding, considers that many of the important conclusions drawn by Dr. Herschell from his very accurate observations are, nevertheless, correct. He therefore agrees with that astronomer that the shining matter of the Sun is not a fluid, but a mass of luminous or phosphoric clouds surrounding the solid nucleus or opaque globe of the Sun; but, instead of supposing this nucleus to be prepared for the reception of inhabitants, he rather

imagines it to be the magazine from which the heat is discharged, while the luminous matter which that heat freely pervades is the region where its light is generated; thus making the interior globe of the Sun to take a capital part in the production of the solar heat. Dr. Brewster supports his theory by very plausible arguments, and opposes very weighty objections to that of Dr. Herschell; some of which, however, seem to have been anticipated, and satisfactorily disposed of by the latter gentleman: it must, however, be acknowledged, that Dr. Brewster's theory seems to be, on the whole, the more ably supported.

The light of the Sun has been found, by Bouguer, to be more intense at the centre of his disc than towards the limb, the very reverse of what might have been expected. For the Sun being a globular body, any portion of his disc evidently subtends a larger angle at the centre than when it is carried round to the limb: as, therefore, under the same angle, a much larger portion of the Sun's surface is comprehended when taken at the limb than at the centre of his disc, the intensity of the light ought to be increased in the same proportion. In order to account for this difficulty, astronomers have supposed the Sun to be surrounded by a very dense atmosphere, through which the rays that proceed from the limb, having to pass in a more oblique direction than those from the centre, are proportionably weakened and dissipated. The luminous aurora, which appears to encircle the Sun's disc in total eclipses, seems to render it extremely probable that he has such an atmosphere.

Another very curious phenomenon, usually ascribed to the atmosphere surrounding the Sun, is the *semita luminosa*, or the luminous path; now better known by the name of the zodiacal light.

This light, which is seen, at certain seasons of the year, a little before the rising, or after the setting of the Sun, resembles the faint light of the milky way, and is so extremely rare, that the stars are visible through it. It is of a pyramidal form, having its base always turned towards the Sun, and its axis inclined to the horizon. The angle at the vertex varies from about 10 to 26 degrees, and its length, counting from the Sun as its base, from 50 to 145 degrees. By the very rapid rotation of the Sun about his axis, it is obvious that the centrifugal[1] force of his equatorial parts must be very great; whereby the parts of his atmosphere, immediately above his equator, will be thrown out to a considerable distance from his surface, while those parts about his polar regions will undergo a correspondent depression, and a lenticular figure, resembling that already described, will be produced. The obliquity of the zodiacal light will, therefore, vary with the obliquity of the Sun's equator to the horizon[2], and, from the circumstance of its being most distinctly seen in spring, when the Sun's equator forms the greatest angle with the horizon, this theory would appear to receive a confirmation almost amounting to certainty. The variation, however, in the length of the cone, and, above all, its extreme elongation, which La Place has shown far exceeds the possible limits of the Sun's atmosphere, are objections so serious, as to leave it very doubtful whether the true cause of this phenomenon has yet been discovered. Cassini, the first person who seems to have made any particular observations upon this

[1] From *centrum* the centre, and *fugio* I flee. The centrifugal force is that force by which all bodies revolving round a centre endeavour to fly off in tangent lines.

[2] From ὁρίζω to limit. The line that terminates the view.

singular appearance, at first supposed it to be caused by an immense number of small planets circulating round the Sun within the orbit of Venus; but he seems very soon to have abandoned this solution for the more probable one of its being caused by an emanation from the body of the Sun, intimately connected with the solar spots, as he always observed it to be most brilliant, when the spots were most numerous.

In concluding this account of the Sun, it may not be amiss to observe, that the character made use of by astronomers to represent this luminary is supposed to be the picture of a buckler, the centre of which represents the umbo, or boss; and the Persians are said to call the Sun by a name which signifies a buckler. The use of characters to represent the heavenly bodies appears to be of great antiquity, and has been supposed to have originated with the professors of judicial astrology, who are said to have adopted them to give an air of mystery to their writings. I am inclined, however, to think, that the use of hieroglyphics among the eastern nations in general, and the Egyptians in particular, sufficiently accounts for the introduction of these symbolical characters.

LECTURE III.

PARTICULAR VIEW OF THE BODIES COMPOSING THE PLANETARY SYSTEM CONTINUED. — OF THE PRIMARY PLANETS. — THE MINOR PRIMARY PLANETS.

Mercury ☿,

The nearest planet to the Sun was, by the Greeks, called στιλβων (stilbon), in allusion to his extreme brilliancy, which exceeds that of any other planet. This word is generally supposed to be a translation of his Chaldee name, which is not now known. On account of his very swift motion, by which he is carried round the Sun at the mean rate of 109,442 miles per hour, he was considered the messenger of the gods, and was by the Romans called Mercurius, the character by which he is denoted being a representation of the caduceus, or golden rod, said to have been presented by Apollo to that deity.

Being so very near to the Sun, Mercury emits a remarkably brilliant white light, and twinkles like the fixed stars, but affords very few opportunities for observation, and, consequently, no very interesting discoveries have been made respecting this planet.

Mercury is about 3224 English miles in diameter, and revolves round the Sun in 87 days, 23 hours, 15 minutes, 43·6 seconds, at the distance of about 37 millions of miles from that luminary. When examined with a very powerful telescope, it exhibits

nearly the same phases [1] as the Moon, being sometimes horned, sometimes gibbous, and sometimes nearly full. By observations on the daily change of appearance in Mercury's horns, its diurnal rotation is found to be performed in 24 hours, 5 minutes, and 28 seconds. Schroeter also detected spots, and even mountains, in Mercury, and succeeded in measuring the altitude of two of them, one of which he found to be ten miles and three quarters in height, being almost three times as high as Chimboraço, the loftiest mountain upon our Earth. The highest mountains are in the southern hemisphere of Mercury.

Venus ♀

Is the next planet to Mercury in the system. In that situation in which she is seen to the west of the Sun, rising before him in the morning, she was, by the Greeks called εωσφορος (eosphorus), the morning star, and φωσφορος (phosphoros), the precursor of day; when she set after him she was called ἑσπερος (hesperos), or the evening star. In the former case, she was by the Romans denominated Lucifer, and in the latter, Vesperus. Among the eastern nations she was worshipped under various names, and is supposed to have been the first planet to which divine adoration was paid. The astronomical character of this planet is said to be a looking-glass with a handle, such being the form of those used by the ancients.

The diameter of Venus is 7687 English miles, and it revolves round the Sun, at the distance of

From φάσις appearance exhibited by any body in its changes, as that of the Moon.

about sixty-eight millions of miles, in 224 days, 16 hours, 49 minutes, 10·6 seconds.

Venus, when viewed with a good telescope, exhibits the same variety of phases as Mercury, and, like that planet, is never seen very far from the Sun, although, at her greatest distance, she is about twice as far from him as Mercury, when in a similar situation. Spots have likewise been perceived upon this planet: they seem to have been first discovered in the year 1665. In 1667 Dom. Cassini, from observations made by himself upon a bright spot which appeared upon Venus, supposed her rotation to be performed in rather more than 23 hours; this result he obtained from observing that the spot, in the course of 24 hours, was advanced about 15° upon her disc, and he concluded that it had, during that time, performed one complete revolution and 15° of another.

In 1726 Signior Branchini commenced a series of observations upon this planet, from which he determines the inclination of her axis to the plane of her orbit to be 15°, and that the north pole of Venus inclines toward the 20th degree of Aquarius. Although this astronomer made some very curious observations upon the spots of Venus, yet they do not appear to have been continued long enough at any one time to detect a sensible change of place in any spot during the time of observation; but in the interval of two and four days he found the same spot so far advanced from its original position, as to warrant the conclusion that it moved on the disc of the planet at the rate of about 15° in a day. This, indeed, would show that Venus revolved on her axis in about 24 days, but it would not prove that this observed revolution was not an excess of one revolution,

over and above 24 other revolutions, which she might have performed during that time; for if at any given time the situation of a spot on the disc of a planet be accurately determined, and in 24 hours after this spot be found to have advanced 15° from its first position, it would not be possible, from such observations, to determine whether the spot, during that interval, had moved forward only 15°, or whether it had performed one complete revolution and 15° of another. Branchini, therefore, perfectly agrees with Cassini that the spots which are seen on Venus advance about 15° in 24 hours, but concludes that this is the whole advance made by those spots in that time, and asserts the true time of the rotation of Venus to be 24 days 8 hours.

Dr. Herschell has also observed spots upon Venus; he likewise remarked an excess of brilliancy about the limb of Venus which resembled a narrow luminous border, and that from this border to the terminator, or line which divides the illuminated from the dark part of her disc, the light appeared to suffer a gradual diminution. From these observations the Doctor infers that Venus is surrounded by an atmosphere which, like our own, he supposes dense enough to reflect and refract light copiously in all directions, and that, consequently, on the border, where we have an oblique view of it, there will be an increase of this luminous appearance. He could, however, never perceive any raggedness in the terminator of Venus, nor any phenomena which denoted the existence of mountains, or by which he could ascertain the period of her rotation, and the position of her axis.

M. Schroeter, from a long course of highly interesting observations upon this planet, has suc-

ceeded in determining the atmosphere and twilight of Venus, measuring the height of several of her mountains, and ascertaining the time of her diurnal rotation. From the appearances exhibited by the cusps[1] of this planet, he has calculated the dense part of Venus's atmosphere to be about 16,020 feet high, and that it is more opaque than that of the Moon; he also supposes the density of her atmosphere to be the reason why we do not perceive those varieties on her surface which are so visible on most of the other planets. Her twilight is 2·25 seconds broad; and by the regular recurrence of certain phenomena, he has determined the revolution of Venus on her axis to be performed in 23 hours, 20 minutes, and 54 seconds, completely confirming the rotation ascribed to her by Cassini. The mountains of Venus, like those of Mercury and the Moon, are highest in the southern hemisphere. On 25th January, 1672, and 28th August, 1686, Cassini imagined he saw a satellite near Venus having the same phase as the planet: several other astronomers, among whom are Short, Baudouin, and Montaigne, have imagined they saw Venus attended by a satellite: they are, however, generally supposed to have been deceived by an optical illusion, as no such phenomenon was witnessed during either of the two last transits of Venus over the Sun's disc.

The Earth is the next planet in the system; but as the telescopic appearances of these bodies form the main subject of the present lecture, without any particular reference being intended to our own situation on the surface of this globe, and

[1] From *cuspis* the point of a spear or other weapon. The point or horns of the Moon, a planet, &c. are called the cusps.

as the magnitude and figure of the Earth, the nature of its atmosphere, &c. are immediately deduced from the phenomena exhibited by the heavenly bodies, as witnessed by an inhabitant of it, I shall reserve these subjects to be discussed in their proper place, and proceed to speak of

Mars ♂,

The next planet, exterior to our Earth, in the system. The ancient Greek name by which he was distinguished is πυροεις (pyrois) fiery, and most of the other ancient names of this planet appear to have nearly the same meaning. His astronomical character is a dart and buckler.

The diameter of Mars is 4189 English miles, and his distance from the Sun, round which he revolves in 686 days, 23 hours, 30 minutes, 35·6 seconds, is about 145 millions of miles. This planet is distinguished from all the others by the singular redness of his light, which has been attributed, by astronomers, to the extraordinary density and extent of his atmosphere, and may be explained upon the same principles as the red appearance exhibited by the Sun, Moon, and Stars, when near the horizon.

The particles of light, not being all of the same magnitude, will not be all refracted in the same degree; for it is evident that the momentum of the largest particles being greatest, they will force their way through a resisting medium with more facility than the smaller particles, whose momentum being less, will of course render them more liable to be turned from their rectilinear direction. Now it has been proved by repeated experiments, that the violet-coloured rays are the smallest, or most

refrangible; the indigo, being next in size, are less refrangible than the violet; the blue than the indigo; the green than the blue; the yellow than the green; the orange than the yellow; and the red, which are the largest of all, are less refrangible than the yellow, or the least refrangible of the whole. In the light, therefore, emitted by any luminous body when it arrives at the eye, the red colour, or that of the least refrangible rays, must of course predominate; and this colour will increase with the number of violet rays which have been obstructed in their passage. Now Mars is ascertained, by the diminished lustre of the fixed stars, when even at some distance from his disc, to have an atmosphere of very great density and extent; and as the light by which he is illuminated has to pass twice through his atmosphere before it reaches our Earth, it must be deprived of a great portion of its violet rays, and consequently exhibit to us a very red and gross appearance. As this will also be the case with every luminous object seen through a mist or cloud, we may form some conjectures of the comparative extent or density of the atmosphere which surrounds the different planets, by the redness of the light they emit.

The very diversified appearance of Mars, when viewed through a good telescope, has rendered it an object of great interest to astronomers. Accordingly, we find that observations of considerable importance were made upon this planet soon after the invention of that instrument. So early as the year 1665 Dr. Hook perceived upon the disc of this planet a considerable number of dark spots, and from the changes of position he witnessed in them, he supposed them to perform a rotation once or twice in 24 hours. From observ-

ations made upon Mars about the same time at Rome, the period of his diurnal revolution was fixed at 13 hours: this decision is, however, censured by Cassini as premature, who, although he discovered that the spots in 24 hours, 40 minutes, returned to the same situation, yet he could not, at first, be positive whether in that time they had performed one or two revolutions. From more accurate subsequent observations, however, Cassini determined that the rotation of Mars was performed in 24 hours, 40 minutes, and supposes that the error of the Italian astronomers arose from the great similarity of the spots on the opposite sides of this planet.

The same result was obtained by Miraldi in 1719, although in the year 1704 he had determined the period of this planet's rotation to be 24 hours, 39 minutes; he also observed that the spots were not always well defined, and that they frequently changed their form. Besides the dark spots, this observer likewise particularly remarked the luminous zone round the south pole of Mars, and which he asserts had been noticed by astronomers full 60 years before. One part of this luminous segment is brighter than the rest; the least bright part undergoes great changes, and has sometimes wholly disappeared. This spot, when most brilliant, appears to project beyond the other parts of his disc, as if it were a portion of a larger globe exactly resembling the bright part of the Moon shortly after her conjunction, when the dark part of her disc is very faintly enlightened by the Earth, and may evidently be accounted for in the same manner. A like luminous zone has been observed in the north polar regions of this planet. Observations upon these bright spots were made by Dr. Herschell, from 1777 to 1783, an account

of which, illustrated by a great many figures, exhibiting the appearance of Mars at different times, has been given by him in the Philosophical Transactions. From these observations, he concludes that the bright polar spots of this planet are produced by the reflections of the Sun's light from its frozen regions, and that the melting of these masses affects those varieties in the magnitude and appearance of the spots which are continually taking place. From the motion of its spots Dr. Herschell has found that the diurnal rotation of this planet is performed in 24 hours, 39 minutes, 21·3 seconds.

From Mars having no satellite, and its appearing to require such an attendant, M. Fontenelle has suggested the probability of this planet being phosphorescent, giving out during the night the light which it had imbibed in the day.

Jupiter ♃,

The next planet in the system to Mars, was by the Greeks called ζευς (zeus), usually said to be derived from ζεω (zeo), although this planet is by no means remarkable for heat. His ancient Greek name φαεθων (phaethon) is taken from his brightness. The character by which astronomers represent this planet is a zeta, the first letter of his Greek name, with a small line drawn through it as a sign of abbreviation.

Jupiter is the largest planet in our system, its diameter being 89,170 English miles. He performs his periodical revolution in 4332 days, 14 hours, 27 minutes, 10·8 seconds, at the distance of 494 millions of miles from the Sun; and revolves on

his axis in 9 hours, 55 minutes, 49 seconds. The most striking peculiarities exhibited by this planet, when examined with a powerful telescope, are belts, or regular stripes, extending across his disc: though subject to considerable variation in number, breadth, and position, yet they are found, for the most part, parallel to the equator of Jupiter, and to each other. Bright and dark spots are also frequently visible in these belts. As some of these last revolve with greater rapidity than others, it may be inferred that they do not all adhere to the body of the planet, although some of them, which, after disappearing for a certain time, re-appear again in the same form and position, may be considered as permanent upon his surface. The spot first discovered by Cassini, in the year 1665, and from observations upon which he concluded the rotation of Jupiter to be performed in 9 hours, 56 minutes, seems, by its long continuance and frequent re-appearance in precisely the same form and position, to be of this kind. The form of the belts, their difference of colour, and the changes which are so frequently taking place in them, Dr. Brewster very plausibly accounts for, by supposing that the atmosphere of Jupiter reflects more light than the body of the planet, and that the clouds of which it is composed, partaking of the very great velocity of its diurnal motion, are formed into strata, accompanied by regular interstices, through which the opaque body of Jupiter, or any of the permanent spots, which happen to lie immediately beneath the opening, become visible.

Jupiter (as has been noticed in enumerating the bodies which compose the planetary system) is always accompanied by four satellites.

Saturn ♄,

The most remote of the anciently discovered planets from the Sun, was called by the Greeks φαινων (phænon) appearing, or shining, and κρονος (cronos) time: the former appellation he is thought to have received from his being less frequently hid by the rays of the Sun than any other planet known at the time he was so named, and the latter from the slowness of his motion. The character by which he is represented is a scythe.

This planet is 79,042 English miles in diameter, revolving round the Sun in 10,759 days, 1 hour, 51 minutes, 11·2 seconds, at the distance of about 906 millions of miles. Saturn, like Jupiter, is attended by a number of satellites, but its most singular appendage, and that by which it is chiefly distinguished from all the other planets, is a luminous ring which encircles his body, and may be classed among the most curious astronomical phenomena with which we are acquainted. Galileo was the first who discovered any uncommon appearance in this planet. Very soon after the invention of the telescope, he observed luminous bodies of an irregular form on each side of Saturn, which he called the *ansæ*, or handles, of the planet. By the aid of more improved instruments, and by combining the variations observable in these luminous appearances with the position of Saturn relatively to the Sun and Earth, Huygens had the merit of discovering that he is surrounded by a broad thin ring. This ring casts a deep shadow upon the planet, the space between which and the ring is rather more than equal to the breadth of the ring itself. This ring, although it appears, when viewed through a telescope of moderate power, to be one solid mass, yet with very ex-

cellent instruments is found to be composed of two concentric rings, having a space of 2927 miles between them. Mr. Short, with a telescope of very high magnifying power, observed the surface of the ring divided by several dark concentric lines, and supposes them to indicate a number of rings proportional to the number of dark lines which he perceived. From the ring appearing to be more luminous than Saturn himself, Dr. Herschell concludes that it is an opaque body equal to the planet in density: he is also of opinion that the edge of the ring is not flat, but of a spheroidal form; and from observations upon certain luminous points which appeared near the extremity of the arms, or ansæ, of the ring, to which they were found to adhere, he has ascertained the rotation of the ring to be performed from west to east in about 10 hours, 29 minutes, 17 seconds, round an axis perpendicular to its own plane, and passing through the centre of the planet.

One of the ansæ has sometimes disappeared while the other remained visible; the two ansæ have also appeared of unequal lengths, and they have even been seen completely detached from the planet, and unequal in size; from which observations it has been inferred, that there are irregularities on the surface of the ring which produce these phenomena. La Place considers such inequalities absolutely necessary to preserve its equilibrium, which otherwise would be subject to disturbance from the slightest external force, such as the attraction of a planet, or comet, which, for want of this self-adjusting principle in the ring, might be sufficient to precipitate it upon the body of the planet.

According to Dr. Herschell, the inner diameter of the smaller ring is 146,345, and its outer dia-

meter 184,393 miles; the inner diameter of the larger ring 190,248 miles, and its outer diameter 204,883 miles. Hence the breadth of the inner ring is 19,024 miles, that of the outer 7317·5 miles, and the vacant space between them is 2927·5 miles. The outer diameter of the larger ring is therefore almost twenty-six times the diameter of the Earth.

The surface of Saturn, like that of Jupiter, is diversified with dark and bright belts, and spots: the belts of Saturn are nearly parallel to his equator, and generally occupy a broader space upon his surface than those of Jupiter do upon the disc of that planet. By changes in the position of dark spots, seen by Dr. Herschell upon Saturn's disc, he has ascertained his rotation to be performed in 10 hours, 16 minutes, 2 seconds, round an axis which is perpendicular to the plane of the ring. The ring of Saturn, therefore, revolves in nearly the same time, and round the same axis as the planet.

Uranus ♅.

This planet is the most remote in our system, to which it may be considered a late acquisition, having escaped observation till the year 1781, when it was discovered, near the foot of Gemini, by Dr. Herschell, who named it the Georgium Sidus, or Georgian Star, in compliment to his munificent patron, King George III.; it is, however, generally known on the Continent by the name of its discoverer, or by that of Ouranus, or Uranus, which, in the heathen mythology, denotes the father of Saturn, whose orbit it includes in the same way that the orbit of Saturn includes the orbit of Jupiter, his reputed son. The existence

of a planet exterior to Jupiter and Saturn, had been conjectured from certain disturbances in their motions, which could not be otherwise accounted for; but the merit of the discovery belongs entirely to Dr. Herschell. The astronomical character of Uranus is an H with a globe or planet pendant from it.

This planet, which is 35,112 English miles in diameter, is 1822 millions of miles distant from the Sun, and revolves round that luminary in 30,737 days, 18 hours. It had been observed by Flamstead and Mayer, but was considered by them as a fixed star, and as such introduced into their catalogues. This planet can only be seen by the naked eye in a very serene sky, when it appears like a fixed star of the sixth magnitude, shining with a bluish white light. The deficiency of the Sun's light upon this planet is in some degree compensated by six satellites, which have been discovered by Dr. Herschell, and it is not improbable that many more remain to be discovered. By reason of the immense distance of this planet, no observations have yet been made upon it, by which the time of its diurnal rotation might be determined.

Having concluded this descriptive survey of the first class of planetary bodies, I shall proceed to speak of the four newly-discovered planets; previ[illegible] to which it may be proper to observe, that [illegible]est distance between the orbits of Mars and Jupiter, so destructive, in one solitary instance, of that general harmony which was known to pervade every other part of the system, induced astronomers, very naturally, to suppose that a planet, hitherto undiscovered, existed somewhere in the interval between them, a conjecture which has been confirmed in a very remarkable manner by the discovery of no less than four small bodies,

which revolve round the Sun between the orbits of Mars and Jupiter. These bodies may, in fact, be considered primary planets, but being distinguished from those already enumerated as such by peculiarities observable in the form and position of their orbits, and especially by their very diminutive size, they may be denominated

MINOR PRIMARY PLANETS,

or, (as Dr. Herschell has called them,)

ASTEROIDS.

Ceres was first discovered at Palermo, in Sicily, by M. Piazzi, on the first of January, 1801, in the constellation of Taurus; Pallas was next discovered by Dr. Olbers, at Bremen, in Lower Saxony, on the 20th of March, 1802; Juno on the 1st of September, 1804, by Mr. Harding, at Lilienthal, near Bremen; and Vesta by Dr. Olbers on the 29th of March, 1807.

Vesta, the nearest of these bodies to the Sun, revolves round him in about 1335 days, 5 hours, at the mean distance of 225 millions of miles; Juno in about 1591 days, at the mean distance of 253 millions of miles; Ceres in about 1681 days, 13 hours, at the mean distance of 263 millions of miles; and Pallas in about 1681 days, 17 hours, at the mean distance of 263 millions of miles.

The diameter of Vesta is not yet known. Schroeter makes the diameter of Juno to be 1425 English miles. The same astronomer makes the diameter of Ceres to be 1624 miles, while Dr. Herschell estimates it at no more than 163. Pallas, according to Dr. Herschell, is but 80 English miles in diameter, while the German astronomer makes it no less than 2099.

These minor planets are also represented by symbols; Vesta by a character resembling an ancient altar with the sacred fire; Juno by the symbol of Mercury, with the superior curves turned the contrary way, and a star between them; the character of Ceres is a sickle, or reaping-hook; and Pallas is represented by the head of an ancient spear.

Upon the discovery of Ceres, astronomers congratulated themselves upon the harmony of the system being restored; the successive discoveries of Pallas and Juno, however, again introduced confusion, and presented a difficulty which they were unable to solve, till Dr. Olbers suggested the possibility of these small celestial bodies being merely fragments of a larger planet, which had been burst asunder by some internal convulsion. The magnitude of these bodies, when compared with that of the other planets, their orbits all being nearly equally distant from the Sun, and their crossing one another in two opposite points of the heavens, viz. in Virgo and the Whale, are circumstances, especially the last, highly favourable to this theory; for if a planet in motion be rent in pieces by any internal convulsion, however various the inclinations of the orbits assumed by the fragments may be, there ought to be two points in opposite quarters of the heavens through which they must all pass in the course of their revolutions; and it was actually in one of these points that Mr. Harding had discovered Juno. For the purpose, therefore, of detecting other fragments of the original planet, Dr. Olbers, two or three times every year, examined all the small stars in the opposite constellations above mentioned, and his labours were ultimately rewarded with the discovery of a fourth new planet, in the northern

wing of the constellation Virgo, which he called Vesta.

Dr. Brewster, in support of this theory, very truly observes, that if a planet be burst in pieces by any *internal* force, capable of overcoming the mutual attraction of its parts, the larger fragments will deviate less from the path of the original planet, while the smaller fragments, being thrown off with greater velocity, will revolve in orbits more eccentric (that is, of a more elliptical form,) and more inclined to the original path. Now the orbits of Ceres and Vesta have nearly the same inclination to the orbit of the Earth as the orbits of some of the old planets, while the orbits of Juno and Pallas are inclined to it, the one in 21° and the other in 34°. Assuming, therefore, those estimates of the magnitudes of these bodies as correct, which best accord with this hypothesis, the Doctor hereupon founds an argument, which he considers almost decisive, in support of the proposed theory of the minor planets; but as the force of this reasoning depends entirely upon the magnitudes of these bodies being such as he has assumed, however willing we may be to admit the theory itself, we are bound, nevertheless, not to allow our decision to be in the least affected by the learned Doctor's argument, till the magnitude of these bodies is accurately determined. Now, according to Schroeter, Pallas, instead of being one of the smallest of these planets, is the largest of the four, and the magnitude of Vesta has yet to be ascertained.

Vesta is the only one of the minor primary planets that can be seen by the naked eye: she appears about the fifth or sixth magnitude, and exhibits a more pure and white light than any of the other three. Juno is of a red colour, and is supposed by Schroeter to have a more dense atmo-

sphere than any of the old planets. Pallas and Ceres are nearly of the same colour, not being so red as Juno; and from the nebulous appearance they present are supposed to be surrounded with an atmosphere of very considerable density and extent. The rotation of these planets has not yet been ascertained.

Owing to the great eccentricity of the orbit of Pallas, it is several millions of miles nearer the Sun, when in perihelion, than Ceres is in a similar part of her orbit. But the aphelion distance of Pallas is several millions of miles greater than that of Ceres, so that the orbits of Ceres and Pallas cross each other. The aphelion distance of Juno is greater than that of Ceres; and the aphelion distance of Vesta exceeds the perihelion distance of Juno, Ceres, or Pallas. The perihelion distance of Vesta is greater than the perihelion distance of either Juno or Pallas. Hence it appears that Vesta may sometimes be more remote from the Sun than Juno, Ceres, or Pallas, notwithstanding its mean distance being less than that of any of the others by several millions of miles; and it also appears that the orbit of Vesta crosses the orbits of the other three.

LECTURE IV.

PARTICULAR VIEW OF THE BODIES COMPOSING THE PLANETARY SYSTEM CONCLUDED.

Of the Satellites.

HAVING, in the preceding lectures, given a full description of the Sun, together with the Primary, and Minor Primary Planets, the Satellites, or Secondary Planets, are the next objects which offer themselves to our consideration. They are, as has been already remarked, eighteen in number, one being the constant attendant on our Earth, four revolving round Jupiter, seven accompanying Saturn, and six shedding their benign influence on the remote Uranus.

The Moon ☽,

That inseparable companion of the globe we inhabit, is the most remarkable, the most beautiful, and, next to that great luminary whose brilliant effulgence she with chastened radiance so copiously reflects, the most useful of all those brilliant orbs which occupy the vast regions of space. The motion of the Moon being the swiftest of all the heavenly bodies, the first computations of time are supposed to have been made by her revolutions; a supposition which seems to be considerably strengthened by the circumstance of her Greek name μηνη (mene) being, as is supposed, the same as that by which she was distinguished among the

Chaldeans, with whom this word signifies to compute, or number, in a general sense. Σεληνη (selene) another of her Greek names, and *luna* her Latin name, are both derived from a word signifying light. Her astronomical character is a crescent[1], or figure of the Moon, about four days old.

The extraordinary apparent magnitude of the Moon arises from her proximity to our own globe, her real diameter being no more than 2180 English miles. When viewed, even by the naked eye, we observe several dark parts, which are evidently caused by unevennesses on her surface. If the eye be kept steadily fixed on the lunar disc for a few minutes together, very brilliant radiations, and spots brighter than the general surface, may be clearly discerned: and when the Moon is examined by the assistance of a telescope of even moderate power, all these appearances become prodigiously increased in number and extent.

Before, however, we proceed to a description of the telescopic appearances of the Moon it will be proper to take notice of a very curious phenomenon, which, requiring no instrument to render it visible, has been very generally noticed, and aptly, though inelegantly, called "the old Moon in the new Moon's arms."

This phenomenon commences with the first appearance of the new Moon after conjunction, or when, being about three or four days old, she is first seen in the evening to the east of that luminary; at which time the body of the old Moon, as it is called, appears faintly illuminated, and the new Moon, or enlightened part of her disc, seems to project beyond the old Moon, and to form a portion of a sphere considerably larger than the unen-

[1] From *crescens* increasing.

lightened part. This appearance has been by some attributed to the difference of effect produced upon the retina by bright objects, and objects but faintly illuminated. Dr. Turin ascribes it to a want of power in the eye to accommodate itself to view objects so remote, and that, for want of this power, the pencils of rays uniting before they reach the retina produce an indistinct and enlarged image of the Moon. Both these theories being founded on arbitrary assumptions, unsupported by experimental demonstration, have been generally rejected as totally unsatisfactory.

A difference of opinion likewise exists concerning the cause of the faint light diffused over the surface of the old Moon. By some, the Moon is supposed to be phosphorescent, and that this secondary light is the spontaneous light which the phosphorescent matter may continue to send forth for some time after it has been excited by the action of the solar rays. Others account for this appearance, by ascribing it to the light of the Sun reflected from the surface of our Earth, which then appears nearly full to the inhabitants of the Moon, (if any such there be,) and, being so much larger than the Moon, reflects the light very copiously upon that planet. In support of this opinion it is also observed, that the phenomenon is most conspicuous at the time of a solar eclipse, when the Earth, as seen from the Moon, being completely illuminated, the greatest quantity of light is reflected; and it is also farther observed, that as the age of the Moon increases, this light becomes more and more faint, till about the seventh or eighth day of her age, when this reflected light entirely disappears, owing to the waning of the Earth, and the increase of her own light, by which

this secondary light is at last completely overpowered.

The thread of light, or lucid bow, which seems to connect the horns of the new Moon, has been quoted, by those who consider the secondary light of the Moon to be phosphorescent, as a convincing argument in favour of their hypothesis. If, they contend, the faint light diffused over the surface of the old Moon were caused by a reflection from the Earth, it would appear most dense near the centre, and gradually weaker towards the edge, quite the reverse of what is observed in the instance of the lucid bow which forms the eastern limb of the Moon; but if, on the contrary, the Moon be supposed to be phosphorescent, the difficulty at once vanishes, and the theory and observation are found in every respect to agree, since it is evident that that part of the lunar orb which has most recently felt the impression of the solar rays (*i. e.* the eastern limb) will continue to glow, and present the lucid appearance already described.

To this explanation of the phenomenon of the lucid bow, it is objected, that were it produced in the way just described, it ought to be broadest in the centre, and gradually tapering towards the horns, whereas it is always found to be the broadest towards the lower part, as at *a*, fig. 10., and narrowest at the upper part *b*, and that when the Moon's western libration is considerable, so as to withdraw from our view a portion of the eastern limb, the continuity of the bow is destroyed, and the part towards *b* is no longer visible. By referring to the map of the Moon, fig. 11., it will be seen that a bright tract, nearly resembling the form of a bow, broadest towards her southern horn, will be found extending itself on the eastern limb, and that this bright portion is separated from the cen-

tral parts by darker regions. From these observations, Dr. Brewster accounts for the lucid bow on the eastern limb of the old Moon, by ascribing it to the accidental circumstance of the Moon's eastern limb being more luminous than the parts adjacent; not, indeed, that the central parts are not equally bright with her eastern limb, but their brilliancy is impaired by their proximity to the illuminated portion. Hence the reason is obvious why the bow is broadest at *a*, and narrowest at *b*, and also how the libration of the Moon withdrawing the narrow part *b* of the bow destroys its continuity. This very satisfactory explanation of the phenomenon first given by Dr. Brewster is so convincing that it is scarcely possible to withhold from it our immediate assent. It is also obvious that it equally obtains, whether the secondary light of the Moon be ascribed to phosphorescence, or to reflection from the Earth. The whole of this subject will be easily comprehended by comparing figs. 10, 11.

When we examine the Moon with a powerful telescope the disc of it is found to be very surprisingly and beautifully diversified with dark and luminous parts, and if our observations be made when she is upon the increase, some very remarkable spots will be constantly found in dark shadow on the side which is farthest from the Sun, and light on that side which is turned towards him; whilst others are always found to be luminous on the side most distant from, and dark on that which is nearest to him. These shadows all decrease in length as the Moon approaches her opposition to the Sun; and when, "full orb'd" she attains her perfect opposition to that luminary, they in a great measure disappear, while her surface presents a number of brilliant points and permanent radiations. During the remainder of her progress they

again appear increasing in length till she is so near to the Sun that she becomes invisible to us: the shadows, however, during the latter period, fall in the opposite direction, or towards the contrary side of the Moon, but still retaining the same distinction, one set of spots continuing to present their dark side to the Sun, and to be enlightened on the side most remote from him, whilst the others have their nearest side illumined by his beams, the opposite side being cast into deep shadow. Besides these particular appearances, great diversities of light and shade are observed to pervade the general face of the Moon. Comparing, therefore, these phenomena with the observed effect of sunshine on our own Earth, and more especially in the elevated and hollow parts of it, astronomers have inferred that the lunar surface is diversified by mountains, plains, and deep caverns. The parts which appear highly illuminated are supposed to be mountains, from their casting shadows in a contrary direction to the Sun, and decreasing in length as the Sun shines more perpendicularly upon them. The luminous portions of the Moon's disc do not, however, all indicate mountains: they are frequently found to be extensive cavities, mostly circular, surrounded by a lofty ridge, and containing an elevated mountain in or near their centre.

The mountainous parts of the Moon are found to exceed in awful sublimity, and terrific grandeur, the similar portions of our own globe. Various means have been devised for measuring the height of the lunar mountains, the most simple of which appears to be that derived from observing the distance from the boundary of light and darkness, at which the Sun's rays strike their most elevated points while they remain in the unenlightened part of the Moon. By this, and various other methods,

it has been ascertained, that many of the lunar mountains are four, and even five, miles in height. The perpendicular elevation of some of those mountains composing that extensive range known by the name of the Appenines exceeds four English miles. The dark parts of the Moon's disc are observed to be smooth, and apparently level, while the luminous portions, as has been already remarked, consist of elevated tracts, which either rise into high mountains, or sink into deep and extensive cavities. The smoothness of the dark portions of the lunar disc has induced some astronomers, very naturally, to infer, that they are immense collections of water: hence the names Crisian Sea, Sea of Nectar, Lake of Dreams, Lake of Death, &c. &c., by which those obscure portions are distinguished; and, notwithstanding the arguments which have been opposed to this opinion, it still continues to be generally maintained by modern astronomers. Those who deny the existence of water in the Moon assert that the dark parts are not exactly level: that, on a minute examination of those parts, inequalities of light and shade, caused by inequalities of surface, are discernible; that in some parts parallel ridges are distinctly visible; and that, when the boundary of light and darkness passes through the large dark spot in the western limb of the Moon, known by the name of the Crisian Sea, this bounding line, instead of being truly elliptical, as it ought to be if the surface were covered with water, is observed to be irregular, and evidently indicates that this portion of the lunar disc is elevated in the middle. Dr. Long, in answer to some of those objections which have been made to the existence of seas, or extensive collections of water, in the Moon, suggests the following queries: "May not the lunar seas and

lakes have islands in them wherein there may be pits and caverns? And, if some of these dark parts are brighter than others, may not that be owing to the seas and lakes being of different depths, and to their having rocks in some places, and flats in others?"

From various irregularities and singular appearances in different parts of the lunar disc, not otherwise to be accounted for, many astronomers have been led to imagine that the Moon is subject to violent volcanic eruptions. This opinion was first maintained by Dr. Hook, and has received the support of many able astronomers. A very singular phenomenon, which seems in a great measure to confirm this conjecture, was witnessed by Don Ulloa during the annular eclipse of 1778. Near the north-west limb of the Moon he observed a white spot, which, from its extreme brightness, had the appearance of an opening through which the Sun was seen; this singular appearance continued for about a minute and a quarter, and was noticed by three different observers. Similar phenomena have been observed at different times by many astronomers, and, among others, by Dr. Herschell, who has witnessed several appearances of this kind, and given us a particular account of his observations upon them. On the 4th of May, 1783, he perceived a luminous point in the obscure part of the Moon, and two mountains which were formed from the 4th to the 13th of that month; and on the 19th of April, 1787, he perceived no less than three volcanoes in different parts of the Moon, two of which he judged to be either at that time nearly exhausted, or about to break out; the third exhibited an actual eruption of fire or luminous matter. On the 20th it appeared to burn with still greater violence than on the preceding night,

and he estimated the burning matter to be above three miles in diameter.

The existence of lunar volcanoes, if admitted, (the evidence of which seems to be too convincing to be hatily rejected,) may be considered as one proof of a lunar atmosphere, since combustion can only take place in atmospheric air; as, however, the existence of the Moon's atmosphere was for a long time disputed, and is, even at the present day, by some made a subject of controversy, it may be proper, concisely to state the principal arguments adduced for and against this opinion. Those who deny that the Moon is surrounded by an atmosphere, rest their opinion chiefly upon the constant serenity of her surface, and the unimpaired brilliancy of the light emitted by the fixed stars and planets, when nearly in contact with the limb of the Moon, and when, if she has an atmosphere, their light, they contend, in passing through it, ought to be visibly impaired. On the other hand, it is urged that her atmosphere, if proportional to the size of the Moon, must subtend too small an angle easily to detect the obscuration of a star or planet in passing through it. The luminous ring, which has been perceived to surround the Moon in total eclipses of the Sun, and which was always observed to be most brilliant on the side nearest the Moon, together with certain red streaks, and other appearances seen near the Moon's limb in solar eclipses, are adduced in support of their theory, by those who contend that the Moon is surrounded by an atmosphere.

The observations of Schroeter, however, seem to have decided this controversy by the complete discovery of the lunar atmosphere. This astronomer having frequently perceived that the high ridges of the lunar mountains, Leibnitz and Doerfel, when

in the dark hemisphere were less illuminated in proportion to their distance from the boundary of light, and having observed corresponding appearances about the cusps of the Moon, together with apparent obscurations and returning serenity, which he attributed to the effect of her atmosphere, concluded that a twilight might perhaps be perceived towards her cusps as he had done in Venus; and this conjecture was at length perfectly confirmed by the discovery of a faint glimmering light stretching from the points of the horns into the dark hemisphere. From the breadth of this crepuscular[1] light, Schroeter has computed that the utmost height of the lunar atmosphere, where it could affect the brightness of a fixed star, or inflect the solar rays, does not exceed 5742 English feet, which space subtending at our Earth, an angle of only 0.94 seconds will be passed over by a star in two seconds of time. The occultation of Jupiter, which took place on the 7th April, 1792, was judged a fit opportunity for confirming the truth of the preceding discovery, and was observed by Schroeter for this purpose. Upon this occasion he found that some of the satellites became indistinct at the limb of the Moon, while others did not suffer any change of colour: the belts and spots of Jupiter appeared perfectly distinct when close to the Moon's limb, and a small luminous spot, though by no means very perceptible, could be plainly distinguished when close to it.

The various appearances in the lunar disc have been accurately represented in maps. The first attempt of this kind was by Riccioli, who portioned out the lunar regions among the most celebrated astronomers and philosophers, by whose

[1] From *crepusculum* the twilight.

names he denoted the various spots on her surface. More correct delineations of the lunar disc, during the whole of her progress round the Earth, were afterwards given by Hevelius in his Selenography. This astronomer distinguished the different parts of the Moon by such geographical names as belong to the several islands, countries, and seas of our Earth, but without regard to similarity of situation or resemblance of figure. The names given by Riccioli are, however, generally adopted, and are those by which the various parts of the lunar surface are usually distinguished by astronomers. As Riccioli and Hevelius both agreed in supposing the dark portions of the Moon to be collections of water, the names appropriated to them by each of these astronomers was in conformity to this opinion. Those by Riccioli seem to be highly fanciful. A map of the Moon, as she appears when full, was drawn by Cassini; but the highly magnified views of the lunar surface by Schroeter are considered the most accurate that have yet been published.

The representation of the Moon, fig. 11., will, it is presumed, be found as correct as the scale upon which it is drawn will possibly admit. I shall, therefore, proceed to point out upon it some of the principal lunar spots, commencing with those larger and more remarkable ones which were supposed, by Riccioli and Hevelius, to be seas, and named by them accordingly. These spots besides having their relative situation described, are distinguished by the letters of the Greek alphabet. The names throughout are according to Riccioli.

α. *Mare Frigoris*, Sea of Cold. — This is a long, irregular dark spot, extending from about 35° E. to 40° W. between 50° and 60° N.

β. *Sinus Roris*, Bay of Dews. — A dark spot at the eastern extremity of *M. Frigoris*, extending in a southerly direction, and in which is Harpalus, &c.

γ. *Lacus Mortis*, Lake of Death. — Faint black spot south of the western extremity of *M. Frigoris*, having annular spots.

δ. *Lacus Somniorum*, Lake of Dreams.—Long, irregular, blackish spot, south-west of *Lacus Mortis*.

ε. *Mare Imbrium*, Sea of Showers. — A very extensive black spot south of the eastern part of *M. Frigoris*.

ζ. *Sinus Iridum*, Bay of Rainbows. — Small semicircular bay on the western side of *Mare Imbrium*.

η. *Palus Nebulorum*, Lake of Fogs. — On the north-western side of *Mare Imbrium*.

ϑ. *Palus Putridinis*, Lake of Putrifaction. — South of *Palus Nebulorum*.

ι. *Mare Serenitatis*, Sea of Serenity. — Very large black spot west of *M. Imbrium*, covered with gentle elevations, and with low ridges, which appear at the time of full moon like streaks of light.

κ. *Mare Crisium*, Crisian Sea. — A large black spot near the western limb of the Moon, high in the middle, with a ridge running from its eastern to its northern margin.

λ. *Palus Somni*, Lake of Sleep. — A pale spot east of *M. Crisium*, containing several small annular ones.

μ. *Mare Tranquillitatis*, Sea of Tranquillity. — Large dark spot south-west of *M. Serenitatis*, the north-east part of it covered with annular spots.

ν. *Mare Fecunditatis*, Sea of Fertility. — Long spot south of *M. Crisium*, stretching from north to south, with rocks and cavities interspersed.

ξ. *Mare Nectaris*, Sea of Nectar. — South-east of *M. Fecunditatis*, intersected with a low ridge.

ο. *Mare Vaporum*, Sea of Vapours. — South-east of *M. Serenitatis*.

π. *Sinus Æstuum*, Bay of Tides. — Small black spots near the centre of the lunar disc, running in a south-westerly direction.

ρ. *Mare Nubium*, Sea of Clouds. — South-east of *Sinus Æstuum*; interspersed with small rocks and cavities.

σ. *Oceanus Procellarum*, Ocean of Storms. — This is a general name for all the large spots between 10° S. and 20° N., and lying E. of 20° E.

τ. *Mare Humorum*, Sea of Moisture. — South of *Oceanus Procellarum*; covered with rocks and ridges on its north-eastern extremity.

υ. *Sinus Epidemiarum*, Bay of Epidemics. — South-west of *M. Humorum*.

Many of the above dark spots, by reason of their great magnitude, may be distinguished on the Moon by the naked eye; but those which follow, being of a description entirely different, cannot be seen without the aid of a telescope. These last, to prevent confusion, are not marked with any letter or figure, but may be readily found by their latitudes and longitudes (as determined by that very accurate observer, Tobias Mayer,) being given.

Pythagoras, 62° 52′ N. 59° 25′ E. — Large annular spot, with annular cavity.

Plato, 51° 14′ N. 9° 12′ E. — Newton, contiguous to its south margin, appears to be the remains of a large annular spot, like Plato. The high mountain, Pico, is one of the remains of its

margin. It is high and rugged on its west margin, with a cavity a little north of it, and another a little to the west.

Aristoteles, 50° 50′ N. 17° 10′ W. — Large and annular, with high rock on its south margin, an annular spot on its west, and rocks on its south-east.

Hercules, 48° 58′ N. 41° 43′ W. — Annular, with central mountain.

Atlas, 47° 11′ N. 47° 0′ W. — Annular, with central mountain.

Heraclides Falsus, 46° 46′ N. 25° 30′ E. — High projecting promontory, with a high rock rising from the plain of the *Sinus Iridum.*

Eudoxus, 44° 39′ N. 16° 24′ W. — Large and annular, with high rocks to the east of it.

Mercurius Falsus, 35° 2′ N. 76° 20′ W. — Large and irregularly annular, with a pointed southern margin, two large central rocks, and two smaller ones; the two largest sometimes appear as one ridge, joining the western margin.

Aristillus, 33° 43′ N. 2° 33′ W. — Deep and annular, with central rock.

Possidonius, 32° 44′ N. 29° 35′ W. — Annular, containing an annular spot near its south margin, and one on its west and north margin, with several rocks.

Autolycus, 29° 46′ N. 2° 31′ W. — Large and deep annular spot, with central spot.

Archimedes, 29° 17′ N. 1° 45′ E. — Large and deep annular spot, with high margin, and high rocks to the south of it.

Cleomedes, 27° 18′ N. 57° 50′ W. — A large annular spot, containing three central rocks, with two contiguous annular spots on its north-eastern, one on its north-western, and two on its western margin. Rocks south-east of it.

Timocharis, 26° 33′ N. 12° 3′ E.—Annular, with central spot, and two luminous radiations from its south margin.

Aristarchus, 23° 40′ N. 47° 2′ E.—A deep cavity, with high rocks, and two cavities east of it, and a radiation issuing from its south-east margin. It is the most luminous part of the full moon.

Seleucus, 20° 50′ N. 62° 40′ E.—Shallow and angular, with central spot. Two luminous ridges pass from it to *Cardanus*, one of them touching the western margin of *Seleucus*.

Menelaus, 16° 25′ N. 16° 5′ W.—Annular, with central mountain, a high rock on its south-east, and two annular spots on its south-west. It is very luminous from its south-west to its north-east.

Plinius, 15° 44′ N. 24° 16′ W.—Annular, with two central mountains. Between *Menelaus* and *Pliny*, stretching southward, there is a singular ridge of rough and luminous ground.

Eratosthenes, 14° 39′ N. 12° 1′ E.—Annular, with irregular central mountains, and curious rocks on its west and east margin, and luminous ridges to the north of it.

Manilius, 14° 34′ N. 9° 2′ W.—Large annular spot, with high margin and central rock.

Marius, 11° 55′ N. 50° 0′ E.—Deep and annular, with a half formed annular spot on its south-east, ridges south of it, and high ground north of it.

Copernicus, 9° 41′ N. 19° 56′ E.—Annular, with a central mountain and broad margin, very luminous all round, with numerous rocks and mountains scattered on the north-east of it.

Kepler, 8° 4′ N. 37° 45′ E.—Very luminous all round, with a central mountain.

Cavalerius, 5° 43′ N. 67° 39′ E. — Annular, and in contact with *Hevelius*.

Hevelius, 2° 10′ N. 68° 13′ E. — Remarkable spot containing a central body like an egg broken at its north end, and a small cavity. Broken rocks east of it, and a singular appearance to the west of it.

Landsbergius, 1° 1′ S. 76° 49′ E. — Annular spot, with a central mountain. Two radiations extend from it to *Rheinhold*.

Ricciolus, 2° 43′ S. 75° 10′ E. — Irregularly annular, with an indented broken margin to the south, dark spots west of it, and a dark spot within it.

Grimaldus, 5° 5′ S. 67° 30′ E. — Irregularly annular, with broken margin.

Hipparchus, 5° 53′ S. 3° 25′ W. — Annular, with small central rocks.

Langrenus, 7° 31′ S. 62° 30′ W. — Annular, with central mountain. Remarkable appearance beyond its south-south-west margin.

Ptolemæus, 8° 57′ S. 3° 11′ E. — Large spot, with irregular margin of different heights.

Theophilus, 11° 25′ S. 26° 28′ W. — Annular, with large central mountain.

Alphonsus Rex, 12° 37′ S. 3° 30′ E. — A deep cavity, with central rock south-east of it. *Alphonsus* is irregular, with a central rock.

Vendelinus, 16° 46′ S. 62° 11′ W. — Irregular, open at north margin, cavity at south margin, mountain at north margin.

Arzachel, 17° 7′ S. 3° 20′ E. — Beautiful spot, with very irregular margin, two central cavities, and a central mountain. Chasms and pits on its margin, chasms north of it.

Bullialdus, 20° 30′ S. 21° 53′ E. — Annular, with high central mountain, and three cavities south

of it. A long ridge runs from its south margin across one of the small cavities south of it, to the half-formed spot west of *Cichus.*

Fracastorius, 21° 22′ S. 32° 31′ W. — Large, hollow, with cavities south of it, and communicating with *M. Nectaris.*

Purbachius, 23° 53′ S. 1[illegible]3′ E. — An annular spot, containing three rocks, with an annular spot on its north margin, and another on its south-east margin.

Petavius, 25° 17′ S. 57° 40′ W. — Annular, with large central mountain. Long and deep chasm on its west margin; rocks north of it; annular spot, with central mountain, north-east of it.

Regiomontanus, 26° 44′ S. 0° 33′ E. — Annular spot, containing two small rocks, and an annular spot on its west margin.

Wernerus, 27° 53′ S. 3° 45′ W. — A large and regular circular spot, with central mountain.

Pitatus, 30° 8′ S. 13° 32′ E. — Half-formed annular spot, with central rock, several marginal cavities, and a cavity communicating with it on the north-east.

Waltherus, 31° 40′ S. 0° 10′ W. — Irregular, with a central rock.

Snellius, 3[illegible] S. 53° 45′ W. — Annular, with central rock, and numerous annular spots east of it.

Furnerius, 35° 34′ S. 58° 10′ W. — Annular, with cavity north of the centre, and spot south of the centre. Singular appearance on its north margin.

Tycho, 43° 0′ S. 10° 48′ E. — A deep brilliant cavity, from which all the radiations in the south limb of the full Moon appear to issue,

Schickhardus, 45° 15′ S. 52° 54′ E. — Numerous cavities on its north, south, and west margins.

Longomantanus, 50° 0′ S. 20° 0′ E. — An annular spot, with a large rock on its north margin, and several on its south-west margin.

Phocilides, 54° 12′ S. 58° 36′ E. — Annular spot on its western margin, and a rock stretching from it across *Phocilides*.

Clavius, 57° 56′ S. 14° 52′ E. — The south marginal spot of *Clavius* has a central mountain in it, and there is a high mountain on its north margin.

The Satellites of Jupiter,

The discovery of which may be considered one of the earliest improvements the science of astronomy has to boast from the invention of the telescope, were first observed, by Galileo. in 1610. They are four in number, and, with the exception of the third and fourth, are never visible to the naked eye; instances of these two being so seen are extremely rare, although they have been known to occur.

When viewed through a telescope, the satellites of Jupiter present a most beautiful appearance, being generally ranged in a straight line, nearly parallel to his belts. That satellite which revolves nearest to Jupiter is called the first satellite; the orbit of the [illegible] includes that of the first; the third is exterior to the second; and the fourth satellite describes an orbit round its primary, which includes the orbits of the other three.

The first satellite completes his periodical revolution in 1 day, 18 hours, 27 minutes, 33 seconds, at the mean distance of 264,490 miles from the centre of its primary.

The second, in 3 days, 13 hours, 13 minutes, 42 seconds, at the distance of 420,815 miles.

The third, in 7 days, 3 hours, 42 minutes, 33 seconds, at the distance of 671,234 miles.

And the fourth, or exterior satellite, revolves round Jupiter in 16 days, 16 hours, 32 minutes, 8 seconds, at the mean distance of 1,180,582 English miles.

From the different periods in which these satellites revolve round their primary, their relative situation with regard to him, and to each other, is continually changing; thus, at one time, they are all seen on the right, at another, on the left of Jupiter, but more commonly they appear divided, one or two being seen on one side, and the rest on the other; nor do they always appear in the order of their respective distances, the second being frequently seen nearer to Jupiter than the first, &c. all which various phenomena, together with the velocity of light, and the method of finding the longitude from the eclipses of these bodies, will be fully explained when we come to consider their motions as seen from the surface of our Earth.

The satellites of Jupiter appear to be of different magnitudes; but as the angle they subtend is too small to admit of their real size being ascertained by actual measurement, attempts have been made to solve this problem, by noting the time which each satellite takes to immerse itself in Jupiter's shadow. From the inaccuracies to which such a method of computation is liable, various results have been obtained by different observers. According to Dr. Herschel, the third is the largest, the second the least, and the first and fourth are nearly of the same size. They are all of them supposed to be considerably larger than the Earth, but their dimensions are not exactly known.

From periodical changes observed in the intensity of their light, Dr. Herschell infers that Jupiter's satellites revolve round their axes, and that the period of their rotation (like that of our Moon) is equal to the time of their revolution round their primary.

The Satellites of Saturn

Are seven in number; of these, five only were discovered before the year 1789, previous to which time the satellites of Saturn, like those of Jupiter, were numbered in the order of their distance from their primary, that being called the first which revolved nearest to Saturn, and so of the rest. When, in the year above mentioned, Dr. Herschell discovered two more satellites revolving round Saturn, interior to any of those already known, these newly discovered bodies, instead of being called the first and second, as by their situation they ought to have been, were denominated the sixth and seventh satellites, so that, in fact, the numbers by which the satellites of Saturn are distinguished neither denote the order of their discovery, nor the proximity of their orbits to the planet round which they revolve. The fourth satellite was discovered, by Huygens, on the 25th March, 1655; the fifth, by Cassini, in October, 1671; the third, on the 23d December, 1672, by the same observer, who had also the merit of discovering the first and second in the month of March, 1[illegible]. The order of their distance from Saturn is, the sixth, seventh, first, second, third, fourth, fifth. The six inner satellites move nearly in the plane of his ring, but the orbit of the fifth makes an angle with the plane of Saturn's orbit of

24° 45′. This last satellite, when at its greatest distance west of Saturn, exceeds all the others, except the fourth, in splendour; but when at its greatest distance eastward it altogether disappears. From the regular recurrence of these phenomena it is inferred, that this satellite, like the Moon, revolves on its axis in a period exactly equal to that of its revolution round its primary.

The sixth satellite revolves round Saturn in 22 hours, 37 minutes, 23 seconds, at the distance of 119,627 miles from his centre.

The seventh in 1 day, 8 hours, 53 minutes, 9 seconds, at the distance of 153,496 miles.

The first in 1 day, 21 hours, 18 minutes, 26 seconds, at the distance of 190,044 miles.

The second in 2 days, 17 hours, 44 minutes, 51 seconds, at the distance of 243,449 miles.

The third in 4 days, 12 hours, 25 minutes, 11 seconds, at the distance of 340,0[illegible] miles.

The fourth in 15 days, 22 hours, 41 minutes, 13 seconds, at the distance of 788,258 miles.

The fifth in 79 days, 7 hours, 53 minutes, 42 seconds, at the distance of 2,297,541 miles.

The sixth and seventh are the smallest of the satellites which attend on Saturn; the first and second are the next smallest; the third is greater than the first or second; and the fourth is the largest of them all.

The Satellites of Uranus,

Which can only be seen with the most powerful telescopes, are six in number, and were all of them discovered by Dr. Herschell; the second and fourth on the 11th January, 1787, and the other four in 1790. It is remarkable that these satellites revolve

in a retrograde direction, or contrary to the order of the signs, in orbits lying nearly in the same plane, and almost perpendicular to the plane of the planet's orbit. The distances and periodic times of the second and fourth of these satellites have been accurately determined; the rest have been calculated upon a general principle hereafter to be explained

The first satellite of Uranus revolves round its primary in 5 days, 21 hours, 25 minutes, 21 seconds, at the distance of 221,155 miles from his centre.

The second in 8 days, 16 hours, 57 minutes, 17 seconds, at the distance of 290,821 miles.

The third in 10 days, 23 hours, 3 minutes, 59 seconds, at the distance of 339,052 miles.

The fourth in 13 days, 10 hours, 56 minutes, 30 seconds, at the distance of 388,718 miles.

The fifth in 38 days, 1 hour, 48 minutes, at the distance of 777,487 miles.

And the sixth in 107 days, 16 hours, 39 minutes, 56 seconds, at the distance of 1,555,872 miles.

In order to illustrate, as far as possible, the description I have now given of the various bodies of which the planetary system is composed, and to assist the imagination in forming a correct idea of the relative magnitudes of the planets, and their comparative distances from the centre of the system, I shall refer to diagram 1, which is composed of seven slides, or pieces, marked A B C D E F G. These being placed on the machine, one upon another, according to the order of the letters, present a general view of the planetary system, on a scale sufficiently large to convey a very just idea of the relative distances of the planets from each other, and from the centre of the system. The magnitudes of the planets, as delineated in the scheme,

are also in due proportion to one another, and to a supposed globe of two feet diameter for the Sun. To give an idea of the distances at which the planets in this diagram must be placed from a Sun of two feet diameter, according to their own proportional bulks, it is only necessary to observe, that the Earth must be upwards of 70 yards from his centre, and the distance of the Moon from the centre of the Earth would be 7½ inches. It is evident, therefore, that the satellites are only represented by their respective primaries, in order to complete the diagram, without any regard to their relative distances from the planets to which they belong. Each planet, having its symbolical character placed against it, renders any farther explanation of the figures in this diagram unnecessary.

LECTURE V.

ON THE FIGURE OF THE EARTH.

In the descriptive survey we have hitherto taken of the bodies composing the planetary system, the introduction of any of those phenomena resulting from our own situation in the universe, has been as far as possible, carefully avoided; nor has the planet itself of which we are inhabitants, been made a subject of particular consideration. Now the Earth being the place from which all our observations must necessarily be made, and the apparent motions of the heavenly bodies, being very considerably affected by the figure of the Earth, and the situation of the observer upon its surface, it will be proper, in order to facilitate our future investigations respecting the planetary motions, to make ourselves acquainted with the true figure of the Earth.

Respecting the form of the Earth, various notions were entertained by the ancient philosophers. Heraclitus, who flourished about 500 years B.C., supposed it was shaped like a skiff, or canoe, very much hollowed; some imagined its form to be that of an oblong cylinder; and others considered it to be in the form of a drum: but the most general opinion seems to have been that the Earth was an immense circular plain, diversified with hills and dales, and every way surrounded by the ocean. When it first began to be considered a globular body is very uncertain, and it is probable, that many long voyages had been performed, ere it was known to

be such, although the Egyptians are said by Diogenes Laertius to have been acquainted with this fact, and also, that the Moon was eclipsed by falling into the Earth's shadow; and Macrobius asserts, that they had not only measured the magnitude of the Earth, but that of the Sun also. That the Egyptians were celebrated for their learning, at least 1500 years before the Christian æra, is evident, since we read that "Moses was learned in all the wisdom of the Egyptians;" now it is generally admitted, that the wisdom here spoken of, refers to their great skill in the science of astronomy; and from their early observations of solar and lunar eclipses, it appears that the figure of the Earth must have been known to them at a very remote period. At what time they first became acquainted with this phenomenon, or whether they were the first discoverers of it, is not worth our while to enquire, it is sufficient for us to know that the rotundity of the Earth is a fact established upon the most irresistible evidence, and to be able to bring forward such proofs in support of it, as cannot fail to convince the most prejudiced, and sceptical mind; a few of the most convincing of which, I shall now produce.

If, standing on the sea-shore, on a fine clear day, we view a ship leaving the coast in any direction, the hull or body of the vessel first disappears; afterwards the rigging becomes invisible, and lastly, the top of the mast vanishes from our sight. Now this phenomenon, is evidently caused by the convexity of the water between the eye and the ship; for were the surface of the sea an extensive plain, the largest and most conspicuous part of the vessel would be visible the longest.

Another proof of the convexity of the surface, is, that the higher the eye is raised, the farther is

the view extended, for an observer in an evening may distinctly see the setting Sun from the top of a lofty tower, or any considerable eminence, after it has ceased to be visible to those below; having appeared to sink below their horizon. It is also very common for sailors from the top of the mast, to discover ships, or land, at a greater distance than they could do when standing upon deck.

On sailing towards the north, the altitude of the pole, and circumpolar stars, is found uniformly to increase, and the inclination of the circles described by all the stars to the horizon, gradually diminishes; in proceeding in a southerly direction, the reverse of all this takes place; the altitude of the pole, with the circumpolar stars decreases, while all the stars describe circles, increasing in inclination to the horizon.

The above observations are chiefly intended to show that the surface of the water is convex: that the continents into which the Earth is divided, are also convex, will evidently appear, when we consider that these vast portions of land, are no where much higher than the seas which intersect them in various directions, or the oceans by which they are surrounded, as is proved by the course of great rivers, such as the river Amazon in South America, and many others. These rivers all run over very extensive tracts of our continents, and discharge themselves into seas, or oceans, yet they are every where navigable, and the rapidity of their stream, which indicates the greater or less inclination of the lands through which they flow, is always such as to show that this inclination is in general inconsiderable, their fall at a moderate estimate, not exceeding one mile in a course of one thousand: their shores are also universally found to be pretty

nearly the same, and no where much elevated above the surface of the ocean.

The foregoing facts afford sufficient evidence of the convexity of the surface, both of the sea and land, in various directions and in different places; yet, perhaps, from none of them, are we entitled to infer that this terraqueous globe is altogether of a spherical form. This opinion, however, seems to admit of a complete demonstration in the case of lunar eclipses, which are caused (as will be hereafter shown) by the shadow of the Earth passing over her disc. This shadow, whatever situation the Earth may be in at the time of the eclipse taking place, is always bounded by a circular line; now it is easy to conceive that a body which in all situations casts a circular shadow, can be no other than a globe; the inequalities of its surface, being too inconsiderable to produce any irregularities in its shadow in eclipses of the Moon; since it can be demonstrated that Chimboraco, the highest mountain on the globe, bears no greater proportion to the bulk of the Earth than a grain of dust does to an artificial globe of moderate dimensions. A still more satisfactory proof of the spherical form of the Earth, is derived from the fact of its having been sailed round by several navigators, who steering their course directly south and west, till they came to the Magellanic sea, and then to the north and west, have returned from the east, to the port from which they sailed; after having experienced all those phenomena which should naturally arise from the rotundity of the Earth.

These and similar observations, having proved the convexity of the Earth's surface, its figure was concluded by mathematicians and astronomers, to be that of a true sphere, excepting only the small inequalities of hills and valleys, on its surface; till

an accident opened a new field for speculation, and drew the attention of Sir Isaac Newton, and Mr. Huygens, to this subject. As, however, the circumstance which led to the discovery of the figure of the Earth not being truly spherical, as well as the cause of its deviation from that form, depend upon the same general principle, from the operations of which, under the impulse and direction of the Omnipotent Being, the whole system of the universe results, it will be necessary in this place, to investigate the form under which this principle operates; or, in other words, to take a general view of the doctrine of gravitation.

Gravity[1] may be distinguished into particular, and general, or terrestrial, and universal.

Particular or terrestrial gravity, is that force by which bodies are continually solicited towards a point, which is either accurately, or very nearly the centre of the terraqueous globe; and may be considered a familiar display of the energies of that powerful but invisible agent in nature, by the effect of which the planets are retained in their orbits.

General, or universal gravity, is that by which all the great bodies of the solar system, and, indeed, all the bodies and particles of matter in the universe, tend towards one another; or, in more appropriate terms, universal gravitation, is that effect of some unknown, but ever active and universal cause, by which every particle of matter gravitates, or has a tendency, towards every other particle. Although the existence of this important and universal principle has been demonstrated, its effects investigated, and the laws to which it is subject explained, and illustrated, by the most cele-

[1] From *gravis* heavy.

brated mathematicians, and philosophers, yet every attempt to penetrate its essence has hitherto proved unavailing.

Terrestrial gravity, more immediately concerning the subject of our present investigations, let us proceed to a contemplation of its effects in those familiar instances which are daily presented to our observation, and which are principally manifested, in the descent of falling bodies, to the Earth's surface.

Now all bodies are composed of what is called matter[1], and the words matter, and body, are frequently, though not with strict propriety, used synonymously. Matter denoting in its primitive sense that unexplained something, which is the the foundation of all bodies, or from which all those things that are objects of our senses are formed, while body (which is of Saxon origin) signifies the material substance of a man, or other animal; and, therefore, ought to be confined to an extended, solid, substance, possessing form or figure.

Matter is of itself perfectly passive, and indifferent as to motion or rest; a body at rest, can never put itself in motion, nor can a body when in motion, of itself alter its rectilinear direction, or fall into a state of rest: in order, therefore, to induce a change of state in any body, from rest to motion, or *vice versa*, it must be acted upon by some external force.

Now, daily experience convinces us that all bodies fall, or have a tendency to fall towards the Earth. Thus a stone, or any other body at rest, if supported by another body, or suspended by a string, discovers this tendency by pressing upon its support, or stretching the string by which it is

[1] In Latin *materia* from *mater* a mother.

suspended; and if the support be removed, or the string cut, it immediately descends to the Earth in a line perpendicular to its surface. Again, if the stone be projected in any direction oblique to the horizon, we see that it is deflected from the right line in which the projection was made, and descends in a curvilinear direction to the Earth. When, therefore, we view these phenomena, and consider the inertness of matter, we are naturally induced to enquire into their cause; and as no visible force was applied to put the stone into motion, or when moving in one direction to alter its course and cause it to assume another, we are led to conclude that these effects must have been the result of some peculiar invisible agency.

Now, since heavy bodies exhibit the same propensity in all parts of the Earth where similar experiments have been made, we are intitled to infer that the cause of these phenomena is to be sought for in the Earth itself; and as we find by experience, that the magnet draws to itself all iron bodies placed within the sphere of its attraction, we may, therefore, by a fair analogy, conclude that it is the attraction of the Earth which causes all circumterrestrial bodies, if unsupported, to fall towards it.

The Earth being a globular body poised in space, can, properly speaking, have no such thing as an upper or under side, since it is on all sides surrounded by the heavens; and as the attractive power of the Earth causes all heavy bodies on its surface to tend towards its centre, the reason why the inhabitants on all parts of the Earth stand equally upright upon its surface, with their feet towards its centre will be evident; namely, because towards that centre the weight or tendency of every man's body is directed, and consequently by the

terms up and down, as applied to the Earth, can only be meant towards the zenith, or towards the centre of the Earth; and, therefore, there is no more occasion to suppose that a person who lives on the opposite side of the Earth to ourselves, is in danger of falling down as it is called into the sky which is under us, than there is to imagine that we are in danger of falling towards that part of the heavens which is immediately over our heads.

Gravity equally accelerates all falling bodies, without regard to their bulk, figure, or quantity of matter, so that abstracting from the resistance of the medium, the lightest and heaviest, the greatest and smallest bodies, would all descend through an equal space in the same time; thus, a sovereign and a feather let fall from the same height, will descend to the Earth in different times in the open air, owing to the resistance of the medium through which they pass, protracting the descent of the feather; but if both be let fall from the top of an exhausted receiver, they both reach the bottom at the same instant, which shows that the force of attraction is always proportionate to the density, and not to the bulk of bodies.

The law by which gravitation acts, is that it decreases as the squares of the distances from the body towards which the gravitation is made increase; a body, therefore, near the surface of the Earth tends towards the centre with four times the force that it would do if it were removed twice as far from that centre; nine times the force that it would do at thrice the distance, and so on; but the distances to which we can have access, either above or below the Earth's sur[illegible] are so small, that it is scarcely possible by an[illegible] experiment upon the weight of a body, to [illegible] any sensible change in the force of gravity [illegible]. We may, therefore, in all

our reasonings concerning the effects it produces at the Earth's surface consider it a constant force, and ascribe the increase of velocity in a falling body not to the attraction of the Earth acting more strongly upon it as it approaches the Earth's surface, but to the continuance of this force.

For the discovery of the law which regulates the descent of falling bodies, we are indebted to Galileo, who found that the space through which every body actually falls in vacuo, is $16\frac{1}{12}$ feet during the first second of its descent in the latitude of London, at the end of which time it has acquired such an increase of velocity as would carry it through double that space or $32\frac{1}{6}$ feet in the next second of time, if the force of gravity were to cease acting upon it; but the velocity continuing to increase by the power of gravity continuing to act upon the body, it actually in this second passes over three times as much space as it passed over in the first second, this added to one makes four; in the third second five times the space which added to the four makes nine, and so on; always increasing by the odd numbers, hence we obtain for the descent of circumterrestrial bodies this simple rule; *the spaces passed over are directly as the square of the times.* Now, as in the first second of time, a body falls through $16\frac{1}{12}$ feet, in order to find the space a body passes through in its descent, we have only to square the seconds and multiply the product by $16\frac{1}{12}$ feet.

To the power of gravity, therefore, considered as a constant force, we are to ascribe the descent of a projectile in a curved line.

Gravity is the property by which bodies are what is termed heavy, and the pressure of any body upon the hand, or whatever supports it, indicates its being *gravis* or heavy. The weight of

any body is the measure of the united gravitation of every particle of matter of which it is composed, and is estimated by means of some known unit of weight with which it is compared. The weight should, therefore, be distinguished from the gravity or heaviness of a body.

In concluding our remarks for the present, upon this grand law of nature, it may be proper to observe that gravitation is an universal principle, and consequently as all bodies gravitate towards the Earth, so does the Earth equally gravitate towards all bodies, and all bodies towards each other; but the attraction of bodies being in proportion to the quantity of matter they contain, the Earth being such an immense aggregate of matter, is supposed to destroy the effect of this attraction between smaller bodies, by forcibly compelling them to itself. The attraction of mountains, however, on plum-lines and the balls of pendulums, has been found by repeated observations to be very considerable.

The effect of this universal principle upon the heavenly bodies is no less important and surprising, than in those objects we have been contemplating, and with which we are most familiar. As, however, to enter upon the subject of universal gravitation in this place, would be in some respects premature, I shall reserve my observations upon that head for a more appropriate opportunity, and shall in the meanwhile resume the subject which led to this digression.

The circumstance alluded to in an early part of this Lecture, as leading to the discovery of the true figure of the Earth was briefly as follows: — Richer, who in 1671 was sent by Louis XIV. to the island of Cayenne, which is only five degrees from the equator, to make certain important astro-

nomical observations, found that the pendulum of his clock which at Paris vibrated true seconds, here lost two minutes and twenty-eight seconds every day, and that in order to make it vibrate exact seconds, it was necessary to shorten it about the eleventh part of an inch.

If the attraction of the Earth were the same at all places, falling bodies would descend in a second of time through equal spaces in all latitudes; and a pendulum clock that shows the true time at Paris, would do the same at Cayenne, and every where else; the motion of the pendulum, like that of all falling bodies, being accelerated by gravity.

Now since heat will lengthen pendulums, and consequently retard their motion, the velocity of which depends on the length of the rod, it might have been supposed at first that this daily retardation was occasioned by the expansion of the rod in a climate so much hotter than that of Paris; it was, however, fully ascertained by repeated experiments made for the purpose, that the heats of Cayenne were by no means sufficient to solve this phenomenon, which could only be occasioned by a diminution in the force of gravity at the latter place.

The attraction of the Earth decreases in proportion to the distance of a body from its centre, and the vibration of pendulums is caused by this attraction; hence it follows that the attractive force of the Earth is least where the motion of the same pendulum (due allowance being made for its expansion by the heat,) is slowest, and that this being the case at the equator, the distance of this circle from the Earth's centre must exceed that of any other part of its surface, and consequently that the Earth is not a true sphere, but an oblate spheroid, flattened at the polar, and swelled out at the equatorial regions.

The oblateness of the Earth at the poles being ascertained, the next point to be determined, was, the ratio between the polar and equatorial diameters. This Newton, upon physical principles, demonstrated to be as 229 to 230; since his time the question respecting the true figure of the Earth, or of any planet revolving about an axis in a given time, has particularly engaged the attention of mathematicians. It would, however, by no means accord with the plan of these Lectures, to enter into an elaborate exposition of the various solutions which have been given of this important and difficult problem, especially as the strict mathematical reasoning employed in the investigation, would be in a great degree unintelligible to many persons for whose use they are intended; let it suffice, therefore, to observe, that although by the actual measurement of a degree of the meridian in different latitudes, as well as by experiments on pendulums made with the greatest care, the compression at the polar regions is placed beyond all doubt, yet there still exists a difference of opinion as to the exact quantity of this compression. Newton, whose investigations were certainly confined to the homogeneous spheroid, assumed, as has been already stated, $\frac{1}{230}$ for the compression at the poles, while La Place makes it $\frac{1}{321}$; it is probable from the most recent experiments and observations, that the true difference between the two diameters is about $\frac{1}{311}$.

Having proved the deviation of the Earth from a truly spherical form, and shown that it is somewhat flattened at the polar, and swelled out at the equatorial regions, I shall now give a very general explanation of the cause of this deviation; in doing which, I shall, without stopping to enquire whether the Earth revolve on its axis or not, assume that

it has such a motion, and proceed to show the effects of this rotation upon its figure.

It is very evident that if any body revolve on an axis, every particle of matter of which that body is composed, must describe a circle, to the plane of which the axis is perpendicular; and that the more distant any part of the earth is from the axis of rotation, the greater will be the circle in which it revolves. The equator, therefore, being the most remote from the axis of rotation, the gravity of the equatorial parts, must be most diminished by the centrifugal force arising from their rapid motion, and this diminution gradually decreases as we approach the poles where it is nothing; consequently if the Earth were originally in a soft or fluid state, it would, by its rotation on its axis, naturally assume its present spheroidal form; or if it were in the first instance a consolidated mass as it is at present, it must have constantly been approximating to that form. A degree of rotation might indeed have been impressed upon it, sufficient to overpower the force of gravity, and cause all bodies to fly off from its surface, in the same manner as the drops of water are thrown from the wheel of a water-mill moving round with great velocity; or by a nice adjustment of the centrifugal force to the power of gravity at the equator, all bodies there might be rendered entirely destitute of weight, so as, although they retained their situation, to exert no pressure on the surface of the Earth: this would be the case if the Earth revolved in 84 minutes 43 seconds, as may be thus proved; let us imagine a satellite close to the surface of the Earth, to revolve round it in the plane of the equator, the square of the time of the revolution of the satellite, would be to the square of the time of the revolution of the Moon, as the cube of the distance of

the satellite, to the cube of the Moon's distance. This proportion is deduced from the last of Kepler's laws hereafter to be spoken of.

The Earth's rotation on its axis, not being performed in so short a time as to produce the above effects, all sublunary bodies continue to be urged towards the Earth by the force of gravity, and retain their situation on its surface, without the least danger of derangement from the action of the centrifugal force; the only effect of which is to produce a diminution of gravity in different latitudes, directly proportional to the squares of the cosines of those latitudes.

I have now endeavoured to show in a clear and intelligible manner, that from the Earth's diurnal rotation, or by the action of a centrifugal force, combined with the influence of gravity, a compression at the poles, and an accumulation of matter at the equator naturally result; and the figure of the Earth, having been demonstrated to be that of an oblate spheroid, we may naturally infer that it has such a motion; of this, however, further proofs will be produced in their proper place: I shall therefore conclude my remarks upon the figure of the Earth, by observing, that what has now been said will be found to apply in a general sense to all the planets in the system.

LECTURE VI.

THE ATMOSPHERE DESCRIBED. — OF REFRACTION. — OF TWILIGHT. — OF METEORS.

The Earth has been mentioned as the place from which all our observations upon the heavenly bodies must necessarily be made; and for the more ready comprehension of the phenomena they exhibit, as seen from different parts of its surface, the figure of this globe has been particularly investigated; it is, however, no less necessary to enquire into the nature of the medium through which they are to be viewed, and to ascertain in what manner, and to what extent, our observations are affected by this medium.

That compound fluid mass which on every side invests our globe, extending to a very considerable height above its surface, is called the atmosphere[1]: it is composed of air, and a heterogenous collection of aqueous and other vapours and exhalations, electric fluids, &c. and may be considered as a vast laboratory in which, by the action of the solar heat, the most important operations of chemistry are continually carrying on.

That part of the atmosphere properly called air, was formerly supposed to be a simple homogeneous and elementary fluid; but by the experiments of Dr. Priestley and others, it is ascertained that atmospheric air is a compound of oxygen or

[1] From ατμος vapour, and σφαιρα a sphere.

pure air, and nitrogen or azotic gas. According to the most accurate experiments, the air that we breathe is composed of only twenty-two parts of oxygen air, and seventy-eight of nitrogen or azotic gas in every hundred.

The uses of this circumambient fluid are as multifarious as they are important; not, however, to dwell upon the numerous advantages mankind derive from it as a mechanical force, a vehicle of sound, or even as the support of all animal and vegetable life, and the great spring of most of those mutations which are continually taking place among sublunary bodies, I shall proceed to consider its properties and effects, as connected, in a greater or less degree, with the science of astronomy.

The atmosphere, in common with all other material substances, is endued with weight and pressure, though in an inferior degree to most other bodies with which we are acquainted; by repeated experiments it is found that the pressure of the atmosphere sustains a column of quicksilver in the tube of the barometer[1] of about 29½ inches in height, and consequently that the whole pressure of the atmosphere is equal to the weight of a column of quicksilver 29½ inches in height, and of an equal base; and because 29½ cubic inches of quicksilver are found to weigh about 15 pounds, therefore the weight of the atmosphere on every square inch of the Earth's surface is equal to about that weight. Again, it has been proved in the case of pumps, &c., that the pressure of the atmosphere balances a column of water of about 34½ feet high, and the cubic foot of water, weighing just 62½ pounds, 34½×62½=2156 pou[illegible] the weight of the

[1] From βαρος, weight, and [illegible] a measure.

atmosphere on a base of a square foot, which, divided by 144, gives nearly 15 pounds for the weight of the atmosphere on a square inch as before. — Now the Earth's surface contains, in round numbers, 200,000,000 square miles, or 5,575,680,000,000,000 square feet; this, therefore, multiplied by 2160, the number of pounds in a square foot, gives 12,043,468,800,000,000,000 pounds for the weight of the whole atmosphere. Mr. Cotes has computed that the pressure of the atmosphere, on the whole surface of the Earth, is equal to the weight of a globe of lead 60 miles in diameter. From the above calculations it appears that a middle sized man, estimating his surface at 14 square feet, sustains a pressure of 30,240 pounds. We are not, indeed, sensible of this enormous external pressure, because all parts of our bodies are filled with this elastic fluid, the spring of which is an exact counterpoise to the weight of the atmosphere, and no more; for any sudden and considerable change in the weight of the air which our bodies sustain, is always very sensibly felt. On the increase of its natural weight, the weather is commonly fine, and we feel ourselves more alert and active than usual; but, on the contrary, when the weight of the air diminishes, the weather becomes bad, because the air has not sufficient strength to bear up the vapours, &c. of which the clouds are composed, and we feel within ourselves a listlessness and inactivity which is commonly, but erroneously, ascribed to the air's being too heavy about us, the very reverse of which is actually the case.

The atmosphere is of an elastic or springy nature, expands and contracts, and is found by repeated experiments, when compressed by different weights, to occupy spaces reciprocally propor-

tional to those weights; or that the more the air is pressed the less space it occupies. It follows, therefore, that the lowest parts of the atmosphere must be the heaviest, as well as the most dense, because they are pressed upon by the weight of all the atmosphere above them, and, consequently, that the air in the upper regions of the atmosphere, must grow continually more and more rare as it ascends higher above the Earth's surface; and this is the reason why clouds and vapours can only rise to a certain height, for where the air in the higher regions of the atmosphere becomes specifically lighter than the clouds themselves, it will, of course, be unable to support them. By a number of very curious experiments, made with the barometer, for ascertaining the density of the air at different heights, it has been proved that a cubic inch of the air we breathe would be so much rarefied, at the height of 500 miles, that it would fill a sphere equal in diameter to the orbit of Saturn.

The following extract, from the writings of the learned Dr. Horsley, so beautifully illustrative of this subject, cannot fail of being acceptable: "If," says this profound and elegant scholar, "the atmosphere of the Earth reaches to infinite heights with finite density, those of Jupiter and every other planet will also reach to infinite heights above the surface of the planet with finite density. The atmosphere of every planet will, therefore, reach to the surface of every other planet, and to the surface of the Sun, and the atmosphere of the Sun to the surface of them all. All these atmospheres will mingle, and form a common atmosphere of the whole system. This common atmosphere of the system will be infinitely diffused, since the particular atmospheres that com-

pose it are so; it will reach, therefore, to every fixed star; and for the same reason, that of every fixed star will reach the central body of our system, and of every other system. The atmospheres of all the systems will mix; the universe will have one common atmosphere, a subtile, elastic fluid, which pervades infinite space; and being condensed near the surface of every larger mass of matter by the gravitation towards that mass, form its peculiar atmosphere."

Before I proceed to speak of the refractive power of the atmosphere, it will be necessary to investigate a little the nature and properties of light, and the general laws of refraction. In this investigation I shall avoid entering largely into the science of optics, extending my remarks no farther than may be requisite to give a just conception of the nature and extent of celestial observations.

Light consists of exceedingly small particles of matter, emanating in all directions from the Sun, a torch, or any other luminous body; and these particles, by striking on our eyes, produce in us the sensation of seeing.

By a ray of light, is meant the least particle of light that can be separately impelled. A pencil of rays, is a parcel of rays issuing from, or proceeding towards a point. A beam of light generally means an aggregate or mass of light greater than a single ray.

The extreme minuteness of the particles of light is demonstrable from the fact, that if a candle be lighted, and no obstacle obstruct its rays, it will fill the whole space within two miles around it, as it were instantaneously, or before the least sensible part of its substance is expended; and it has been computed, that upwards of six billions of times as

many grains of light are emitted by a burning candle in one second of time, as there are grains of sand in the whole Earth, supposing every cubic inch of the Earth to contain one million of such grains. Another proof of the minuteness of these particles is adduced from the facility with which the rays of light penetrate glass, crystal, and other solid bodies, without the smallest diminution of their velocity. The exility of the particles of light, is still farther proved by the circumstance of their not being able to disturb the smallest particle of dust which they may chance to encounter in their progress, notwithstanding the inconceivable velocity with which they move.

The rarity of light, and the minuteness of its particles are indeed truly astonishing; yet the velocity with which it moves is no less surprising. A cannon-ball, moving at its ordinary rate of about 480 miles *per* hour, would take no less than twenty-two years, two hundred and eleven days, to traverse a space which is passed by a particle of light in eight minutes, seven seconds of time; light travelling with the immense velocity of 195,072 English miles *per* second, whereby the rays of light pass from the Sun to the Earth (a distance of nearly 95,000,000 of miles) in eight minutes, seven seconds, as will hereafter be shown. Now the force with which moving bodies strike, is in proportion to their masses, multiplied by their velocities, and it has been already shown that light moves at the rate of 195,072 miles *per* second, which is 1,463,034 times swifter than the motion of a cannon-ball. If, therefore, 1,463,034 particles of light were equal in bulk to an ordinary grain of sand, their effect upon our visual organs would be equal to that of sand shot point blank from the mouth of a cannon.

Light is sent back, or reflected, by what are called opaque bodies, or those which have no power of emitting light in themselves; thus the Moon and planets are opaque bodies, and shine by reflecting the Sun's light. But whether emitted or reflected, light always moves in straight or direct lines; this may be proved by looking into a bent tube, which evidently obstructs the progress of the rays of light in right lines.

By a medium is meant any transparent body which suffers light to pass through it, as void space, air, water, glass, &c.; these mediums of course differ in density.

Light, consisting of material particles, must of course be subject to the laws of attraction, by the superior influence of which its propensity to move in a direct line is, in certain cases, overcome. To effect this it is necessary, first, that the rays of light should pass out of one medium into another of a different density, or of a greater or less degree of resistance; and, secondly, that they pass in an oblique direction. When under these circumstances a ray of light is bent out of its natural course, it is said to be refracted, or broken.

The angle of incidence is the angle made by a ray of light, and a line drawn perpendicular to the refracting surface at the point where the light enters that surface; and the angle of refraction, is the angle made by the ray in the refracting medium with the same perpendicular produced.

A ray of light passing from a rarer medium into a more dense one, is refracted towards the perpendicular; on the contrary, a ray of light, in passing from a dense medium into one more rare, is refracted from the perpendicular. These general laws of refraction may be familiarly illustrated by

the following simple experiments: —Let a lighted candle shine obliquely into an empty basin, and mark the place where the shadow of the side nearest the candle falls, then if the basin be filled with water, without moving either the candle or basin, the shadow will be found to fall in the bottom of it considerably more towards that side nearest the light than it did before. Now vary the experiment by placing a piece of silver or shining substance at the bottom of the empty basin; and, retiring from it till you just lose sight of the silver piece, let another person fill the basin with water, the piece of silver will re-appear, although no change of position has taken place, either with regard to the silver piece or your eye. In the first of these experiments, upon the water being poured into the basin, the ray passes from the air into the water, which being a denser medium, the ray is refracted downwards, or towards the perpendicular; in the latter instance the ray proceeds from the water into the air, and the water being the denser medium, the ray, on leaving it, is bent from the perpendicular, or towards the eye of the spectator. This accounts for the apparent distortion of bodies when dipped in a fluid, as a walking-stick, for instance, which upon being thrust partly into the water in an oblique direction, appears broken; it also shows why, standing by the side of a river, the bottom of it appears to us nearer than it really is.

The more obliquely the ray enters the refracting medium, the greater is the refraction, and *vice versa*. Therefore, when the ray strikes the surface perpendicularly, no change of direction takes place. The denser that any medium is, the greater is the refraction the rays of light suffer in passing through it.

Having explained the most remarkable properties of light, and given a general idea of the refraction it undergoes in passing from one medium to another of a different density, let us proceed to apply these principles to the heavenly phenomena, by showing what change the light emitted from the Sun or planets undergoes in passing through that immense refracting medium, our own atmosphere, and how this change affects our observations upon these bodies.

The height of the atmosphere, at which it is dense enough to refract the rays of light, is about fifty miles, and it increases in density (as has been already demonstrated) towards the surface of the Earth. Now let E, *fig.* 12., represent the Earth, H O R the sensible horizon, and the space between C O D and A *m* B the atmosphere. Suppose M *m* to be a ray of light from the Sun, and *m* the point where it enters the atmosphere. At this point (the atmosphere being more dense than the etherial regions above it) the ray of light suffers refraction, or is bent downwards or towards the perpendicular, and were the atmosphere of equal density, the ray would, from this point, proceed in a right line to the surface of the Earth; but the density of the atmosphere increasing as it descends, the ray of light will be every instant more and more refracted, and will describe the curve *m* O, increasing in curvature as it approaches O. But since an object is always seen in the direction in which the rays of light from it enter the eye of the spectator, the Sun will appear at N, in the direction of the tangent to the curve at the point O, with which the last elementary portion of the curve at O will of course coincide. Hence it is evident the effect of refraction is to increase the apparent altitude of all the celestial

bodies. Now it has been already declared that the more obliquely a ray of light enters a refracting medium, the greater will be the refraction. As, therefore, the rays of light from an object in the horizon enter the atmosphere more obliquely than in any other situation, the horizontal refraction must obviously be the greatest; as the altitude of the object increases, the refraction gradually diminishes, and when the object is in the point immediately over the head of the observed, as at *z*, the rays entering the atmosphere in a perpendicular direction, the refraction is nothing. The angle of refraction is the difference between the true and apparent altitudes of the body.

Refraction having the effect of making all the heavenly bodies appear higher than they really are, causes those bodies frequently to appear above the horizon, when they are really below it: the Moon has even been seen eclipsed above the horizon, while the Sun was distinctly visible: which must evidently be caused by refraction; for since eclipses can only take place when the Sun and Moon are in diametrically opposite points of the heavens (as will hereafter be demonastrted) they could not both be visible at the same time. The horizontal refraction, indeed, is sufficient to produce this effect, being at a mean state of the atmosphere 30′ 51″, which is nearly equal to the apparent diameter of the Sun: this is also the reason why the length of the longest day exceeds that of the longest night. The oval form of the Sun and Moon, at rising and setting, is to be attributed to the same cause, for the lower limb of either of those bodies being more refracted than the upper, causes a decrease in its perpendicular diameter, while the transverse or horizontal diameter remains the csame. For this reason, also,

the vertical distance between any two stars near the horizon, accurately measured by any instrument, is found to be considerably less than when they are at any considerable elevation, the lowest star being most affected by refraction. If the circle in which the two stars are placed be parallel to the horizon, their apparent distance is also less than the true; for as the effect of refraction is to make them appear in a more elevated parallel than that which they really occupy, and as these parallels become less and less in proportion to their elevation above the horizon, it is obvious that the distance between any two stars diminishes in the same proportion. Tables of refraction for different heights are constructed by taking the altitude of circum-polar stars, when they come to the meridian above and below the pole: the refraction being much greater when they come to the meridian below the pole than above it, it is clear that the true elevation of the pole is not an arithmetical mean between these two altitudes of the star; the refraction for different altitudes is therefore ascertained by observations upon stars at different distances from the pole. As, however, refraction depends entirely upon the density of the atmosphere, which varies with the temperature, different kinds of vapours, quantity of moisture, &c. it may contain, it is evident that these tables can exhibit only an approximation to the truth; the numbers in them must therefore be corrected according to the state of the barometer and thermometer at the time of observation, or for which the refraction is wanted. Tables of refraction for different altitudes, with the necessary corrections for the state of the barometer and thermometer, are to be met with in most treatises on astronomy.

The greater the condensation of the air the more is its refractive power increased; accordingly, its effects are found to be most considerable in cold weather and in high latitudes.

The effect of refraction upon terrestrial objects, seen at a great distance, is also similar to those effects already mentioned, and often gives rise to very singular appearances.

Besides the refractive power of the atmosphere, which has now been described, it is endued with a reflective power, by which part of the Sun's light is thrown back to the Earth, while his direct rays are intercepted by the horizon. This takes place both before the Sun rises in the morning, and after he sets in the evening; and the faint light thus produced is called the twilight, or crepuscular light.

The twilight usually begins in the morning when the Sun is within 18° of the horizon, and ends in the evening when he has sunk 18° below it. It is of the longest duration when the apparent path of the Sun in the heavens is most oblique to the horizon; this, as will hereafter be seen, takes place in winter and summer, when his declination being great, his perpendicular distance from the horizon increases slowly. In spring and autumn, when the Sun is near the equator, the twilight is of short duration, because the Sun's distance from the horizon rapidly increases. The higher the latitude, therefore, the longer the twilight continues; the effect of this is, however, in some degree counteracted by the following circumstances. It is to be observed that the atmosphere, enveloping all parts of our globe, if they both continued at rest, and had no rotation about a common axis, would, by the laws of gravity, be perfectly

globular; but as the Earth and the circumambient parts of the atmosphere revolve uniformly together about their axis, the different parts of both have a centrifugal force, the tendency of which being more considerable as the parts are more remote from the axis of rotation; the figure of the atmosphere is effected in the same manner as I have, in a former Lecture, shown the figure of the Earth to be, and consequently becomes an oblate spheroid; the parts that correspond to the equator being farther removed from the axis than the parts which correspond to the poles. The temperature of the atmosphere also assists to produce this effect; for heat, by its expansive power, having a natural tendency to increase the height of the atmosphere, it is evident that from this latter cause the evening twilight ought to be of longer duration than the morning, and from both, that the twilight at the equatorial regions should exceed that of higher latitudes; the evening twilight at the equator ought, therefore, were these the only circumstances to be considered, to be the longest possible. The duration of twilight in our latitude is found to be the shortest about the beginning of March, and towards the middle of October.

We have now investigated, at some length, those properties of the atmosphere immediately connected with the science of astronomy; and were we stepping aside, as it were, from our prescribed path, to enter into the detail of all the wonders it contains, we should in this, as in every part of the creation, find an inexhaustible field for admiration and deep research. Here the vital principle exists, and here the source of that universal decay which takes place among all sublunary bodies is to be met with: in this ever-

varying scene, corruption and dissolution are continually taking place; and it may indeed be considered the region of wonders, and the vast theatre in which all those surprising phenomena, known by the general name of meteors, are exhibited. And since these appearances, though they are not, perhaps, strictly speaking, of an astronomical nature, seem to be, at least in some degree, related to the heavenly phenomena in general, I shall conclude this lecture with a very concise description of some of those meteors which seem to be the most curious and interesting.

The term Meteor is, indeed, by some writers, restricted to luminous bodies appearing at uncertain times, and with more or less motion, in the atmosphere. In a more extended sense, however, it comprehends all the visible phenomena of meteorology. One of the most beautiful of these is that well-known phenomenon, called, in poetical language, the Iris, but more generally denominated the Rainbow. For the explanation of this appearance we are indebted to Sir Isaac Newton, who demonstrated it to be occasioned by the reflection and refraction of the rays of light in the cloud in which it is perceived. It assumes a semicircular appearance, because it is under certain angles that the refracted rays become visible; these are, however, so dependent upon the situation of the eye, that if the spectator alter his station he will still see a bow, but not the same bow he saw before, and if there be several spectators, each will see a different rainbow. The angle between the incident and emergent rays being different for the different colours, the seven primary colours observable in this bow arise from each being reflected under the angle in which alone it can become visible. In order that a rainbow may be

seen, the spectator must be placed between the shower and the Sun, which last must be elevated at least 42° above the horizon.

A secondary, or false bow, occasioned by a double refraction and reflection of the rays of light, is sometimes seen, appearing externally to embrace the primary bow; in this, however, the colours are not only fainter, but what is most remarkable, are arranged in an inverted order, in consequence of the light entering at the inferior parts of the drops of rain, and being transmitted through the superior. The colours of this exterior bow are fainter than those of the other, because the drops being transparent, a part of the light is transmitted, and consequently lost, at each reflection.

The phenomenon called the Marine Bow is sometimes observed in a very agitated sea, when the wind sweeping part of the tops of the waves, and carrying them aloft, the Sun's rays falling upon them are refracted and reflected, as in a common shower, and the appearance of the bow produced in a manner altogether similar.

Bows have even been seen on the grass, formed by the refraction of the Sun's rays in the morning dew.

The halo, or corona[1], is a luminous circle surrounding the Sun, the Moon, a planet, or a fixed star. It is generally perfectly white, but sometimes coloured like the rainbow: those which have appeared round the Moon or stars are usually of a very small diameter, but those about the Sun are of various magnitudes, and sometimes immensely large. In those which are coloured, the colours are fainter than those of the rain-

[1] From *corona* a crown.

bow, and seem to undergo every diversity of arrangement.

Parhelia[1], or mock suns, occasioned, like the halos, by the reflection and refraction of light, are very brilliant appearances, and sometimes almost equal the luminary himself in splendour; they are generally about the size of the true Sun; but when several of them appear at once they are not equally luminous. They are externally tinged with colours like the rainbow, are not always circular, and are sometimes accompanied by a long train of light or tail, in an opposite direction to that of the Sun, and growing paler as it approaches the extremity. Dr. Halley observed one with tails extending both ways, and Mr. Weidler observed a similar phenomenon, one tail being directed up and the other downwards. Parhelia are generally accompanied by coronas, and sometimes by a large white circle parallel to the horizon, passing through all the parhelia, and which, if entire, would pass through the centre of the Sun.

Paraselenæ[2], or mock moons, have been sometimes observed, but these, like the parhelia, very seldom occur.

Falling stars are generally supposed to be composed of the hydrogen gas produced in marshes and stagnant waters. This gas, rising into the upper regions of the atmosphere, and being of a very inflammable nature, is there ignited by electricity, producing those meteors commonly called falling or shooting stars.

Fire-balls are a class of meteors which were regarded by the ancients as the infallible har-

[1] From παρά with, or in addition to, and ἥλιος the Sun.
[2] From παρά and σελήνη the Moon.

bingers, or indications, of great and awful events in the moral and political world. These phenomena, although they are sometimes seen in the temperate climates of Europe, are far more common and stupendous in the tropical regions. Most of these meteors are nearly round, are frequently seen at a very great elevation above the surface of the Earth, and travel with an immense velocity. One of these, seen in this country in the year 1783, an account of which appeared in the Philosophical Transactions of the following year, had the appearance of a luminous ball, which rose in the N. N. W. nearly round; it soon after became elliptical, and gradually assumed a tail as it ascended, and in a certain part of its course seemed to undergo a remarkable change, compared to bursting, after which it was apparently divided into a cluster of balls of different magnitudes, and all carrying or leaving a train behind; till, having passed the east and varying toward the south, it gradually ascended and disappeared. This meteor was seen in all parts of Great Britain, and even as far as Rome, and is supposed to have described a tract of 1000 miles at least over the surface of the Earth. The splendour of these meteors is frequently so great as totally to obliterate the stars, and cause the Moon to look dull and red, occasioned, perhaps, by the contrast of colour, as these meteors always shine with a bright blueish flame. They sometimes disappear without any explosion, though this is not generally the case, almost all the larger fire-balls having been observed to disappear with very great ones, at which time heavy stony substances have fallen from them.

These are denominated meteoric stones; and though accounts of the descent of these bodies had from time to time been published, they were

long discredited: the most irresistible proofs of these bodies having fallen from the atmosphere have, however, been obtained; and many of those which have fallen in different places have been analysed with great precision by Howard, Vauquelin, and others.

These stones contain silex, sulphur, nickel, &c., and exactly resemble one another, both in internal composition, and external appearance, although entirely different from every other mineral production of the countries in which they are found. Most of these stones have been preceded by the appearance of such luminous bodies or meteors as have been described, which bursting with an explosion the shower of stones ensues. These stones sometimes continue luminous till they sink into the Earth, but most commonly this luminous appearance vanishes when the explosion takes place.

The origin of meteoric stones has never been satisfactorily accounted for. Dr. Chladni supposes the meteors from which they fall were bodies floating in space, unconnected with any planetary system, attracted by the Earth in their progress, and kindled by their rapid motion through the atmosphere. La Place is of opinion that these stones are projected by lunar volcanoes, within the sphere of terrestrial attraction. The arguments employed by this able astronomer in support of this hypothesis are too long to be introduced in this place, and would, perhaps, at last barely prove that this origin of aerolithes[1] comes within the limits of possibility. The most prevalent opinion among modern philosophers is, that they are concretions actually formed in the atmosphere itself,

[1] From ἀήρ air, and λίθος a stone.

and this supposition certainly appears to be the most probable, although perhaps the manner in which these stones are formed will for ages remain mere matter of conjecture.

The Ignis Fatuus, or Wandering Fire, called also Jack with the Lantern, and sometimes Will o' the Wisp, is a meteor far better understood than the one last mentioned; philosophers being generally agreed in ascribing this appearance to some volatile phosphoric vapour, it being usually visible about damp places, burying-grounds, &c., where phosphoric matter may be presumed to abound. The motions of these meteors are very irregular, sometimes sinking towards the Earth, sometimes totally disappearing: they frequently change their colour, expand, or contract, generally grow fainter as any person approaches, and vanish entirely if any one comes very near to them, appearing again at some distance. Dr. Shaw describes one seen by him in the Holy Land, which seems to have been of a rather peculiar kind. This meteor was sometimes globular, or in the form of the flame of a candle, and immediately afterwards spread itself so as to involve the whole company in a pale light, entirely destitute of heat; it then contracted itself and suddenly vanished: in less than a minute it again became visible, running along from place to place, or expanding itself over more than three acres of the adjacent mountains. The atmosphere he describes as thick and hazy at the time.* Sir Isaac Newton defines the ignis fatuus, "a vapour shining without heat."

The Aurora Borealis, Northern Lights, or Streamers, is a kind of meteor seen in the northern parts of the heavens, and is most conspicuous in the winter and in frosty weather. This meteor presents a most interesting appearance; and by its

constant effulgence the traveller in Lapland and Sweden is furnished with a brilliant light during the whole night. In the north-eastern parts of Siberia, these Northern Lights are said to assume a peculiarly grand appearance, which generally commences with single bright pillars rising on the north and north-east; these gradually increasing comprehend a large space of the heavens, rushing about from place to place with incredible velocity, till at length they nearly cover the whole sky, causing the heavens to appear like one vast dome, glittering with gold, rubies, and sapphire. The hissing noise which accompanies this truly imposing spectacle adds to the awful sublimity of the scene. Mr. Cotes attributes this phenomenon to streams emitted from the heterogeneous and fermenting vapours of the atmosphere; it is, however, more generally ascribed to electricity.

I have now described the principal of those phenomena usually termed Meteors; and as in so doing I have already extended this Lecture beyond my usual limits, my observations upon those yet remaining to be spoken of will be comprised in a few words.

The vapour raised by the heat of the Sun during the day from the surface of the Earth and waters, being condensed by the cold of the night, descends in the form of what is called Dew, which, if the cold be severe enough to freeze the particles that compose it, becomes hoar-frost.

Snow is formed by a regular process of crystallisation among minute frozen particles of water floating in the air; and from the structure of a crystal of snow it is evident that a drop of rain is formed by the junction of a great number of smaller drops. When these come suddenly together in the act of freezing they form a nucleus of

ice, of a spongy texture; this, in passing through a large portion of vapours in its descent, becomes encrusted with clear ice, and constitutes hail in the form we usually see it: when the nucleus falls unencrusted it may be considered an indication of severe frosts.

Thunder and lightning are phenomena, the effects of which are too well known to need any description. The cause of thunder is the same with that which produces the ordinary phenomena of electricity: the cloud which produces the thunder may be considered as a great electrified body; if, therefore, this meet with another cloud, which is either not electrified, or electrified in a less degree than itself, the electric matter flies from all parts towards this cloud, and thus the flashes of lightning and the report of thunder are produced.

The last meteoric phenomenon I shall notice is the water-spout. This is an aqueous meteor common in the tropical seas, and sometimes seen in our own: they have also, though not so frequently, been observed on land. This formidable phenomenon is, by the majority of philosophers, attributed to the same cause as that by which a whirlwind is produced on land. If, by any extreme and sudden rarefaction of the air a vacuum be produced over any part of the surface of the sea, the atmosphere which presses powerfully and equally upon every other part of the surface forces the water to rise up in the vacuum, which ascends to the clouds in a column or canal, as thick as a man's finger, his arm, and sometimes his whole body; having reached the cloud which hangs over it, it spreads out like the mouth of a trumpet and mixes with it, and in some cases perhaps produces the cloud itself. These phenomena last for several minutes, the canal then lessen,

by degrees till it altogether disappears, when the sea about it resumes its level. If one of these water-spouts fall upon a vessel, the force and quantity of its waters are sufficient to destroy the rigging, inundate the ship, and sink it in the deep. To avoid these fatal consequences sailors, when they observe the approach of a water-spout, generally endeavour to break it by firing at it before it comes too near the ship. These terrific meteors have also been known to commit great devastation by land.

LECTURE VII.

A GENERAL VIEW OF THE APPARENT MOTION OF THE HEAVENS AS SEEN FROM DIFFERENT PARTS OF THE EARTH'S SURFACE.

FROM the very comprehensive view of the bodies composing the planetary system contained in the preceding Lectures, we shall be naturally led to enquire into the motions of those bodies, and the various phenomena to which they give rise. In illustrating these subjects I shall first give a brief sketch of the apparent motions of the heavenly bodies in general as viewed from different parts of the Earth, and shall then proceed to give a full explanation of the phenomena peculiar to each body or class of bodies of which the planetary system consists. That these subjects may be fully understood, it will be proper to commence with an explanation of certain astrononomical terms, which are likely to occur in the course of our investigations.

If a spectator be placed on some extensive plain, with no intervening object to interrupt his view, he will find his prospect terminated by a vast circle in which the earth and heavens seem to meet. From this circle, which is called the Sensible Horizon, the heavens will appear to rise like a vast hemispherical vault over his head. The Rational Horizon is a circlet the plane of which is imagined to pass through the centre of the Earth, parallel to the plane of the sensible horizon, and

like that to be extended in every direction to the sphere of the heavens, which it divides into two equal parts or hemispheres. The Earth, although a body of great magnitude, is but a mere point in comparison of the immense distance of the starry heavens, and consequently these two parallel circles, though really a semidiameter of the Earth distant from each other, may be reckoned coincident in the sphere of the heavens, the distance between them being too small to be measured by the most accurate astronomical observation; hence it is that every observer will constantly have one half of the heavens above and the other below his horizon; the former is therefore called the visible, and the latter the invisible hemisphere.

The poles of the horizon are called the Zenith[1] and Nadir: the Zenith is the vertical point, or that point of the heavens immediately over the head of any person: the Nadir is that point of the heavens directly under his feet; hence it is evident that with regard to two persons inhabiting diametrically opposite parts of the earth these are convertible terms, that point of the heavens which is the zenith of the one being the nadir to the other, and *vice versa*.

Almacanters[2] are circles supposed to be drawn in the celestial sphere parallel to the horizon; and because the altitude of any heavenly body is greater or less as the almacanter in which it is situated is further from, or nearer to the horizon, these circles are frequently termed Parallels of Altitude.

[1] The terms Zenith and Nadir are corruptions of two Arabic words, one signifying the vertical point, and the other the point opposite to the vertex.

[2] From *Almokenter*, a word partly Greek and partly Arabic, signifying a circle having its centre in the same axis with another.

If we imagine a number of circles to be drawn through the zenith and nadir of any place, these circles, which will of course be perpendicular to the horizon of that place, are called Vertical[1] Circles: those which intersect the horizon in the east and west points being denominated Prime Verticals. That vertical circle which passes through the north and south points of the horizon is termed the Meridian; and since the altitude of any heavenly body or its height above the horizon is the arc of a vertical circle intercepted between that body and the horizon, the altitude of any body situated on this vertical is called its meridian altitude.

Vertical circles are also called Azimuths[2], and sometimes Secondaries to the horizon; and in general any great circles which are imagined to pass through the poles of another great circle are termed Secondaries of that circle.

The time that elapses between the rising of any heavenly body and its arrival at the meridian is called the Semidiurnal Arch: the distance of that point of the horizon on which any object rises or sets from the east or west points of the horizon is called its Eastern or Western Amplitude; and the arch of the horizon intercepted between the meridian and the vertical circle passing through any object is called its Azimuth, and is equal to the angle at the zenith formed by the meridian and vertical circle; the azimuth of a star when in the horizon being the same with the compliment of its amplitude. Hence vertical circles are also called Azimuth Circles, or Azimuths.

The ecliptic has been shown to be inclined to the equator at an angle of about 23° 28′, and there-

[1] From *vertex* the point over head.
[2] From an Arabic word signifying a point or mark.

fore the poles of these circles must be 23° 28′ distant from each other. A great circle passing through the poles of the ecliptic and the equator is called the Solsticial Colure[1], and another great circle at right angles to the former, and passing through the poles of the equator and the points Aries and Libra, or the equinoctial points, is called the Equinoctial Colure.

The rising and setting of the heavenly bodies, or their ascent above, and descent below the horizon of any place, together with their apparent motion through the visible hemisphere, are the first phenomena which arrest the attention of an inhabitant of the Earth. It is, however, to be observed, that those appearances do not take place under precisely the same circumstances at all places on the Earth's surface. For the Earth being a globular body places may be either under the equator or the poles, or they may be between both; and according as places are thus differently situated so will the heavenly bodies appear to an inhabitant of any one of them to revolve round the earth once in twenty-four hours, in a manner very different from that in which they will appear to move to an inhabitant of either of the other two. An observer any where on the equator will have both the celestial poles in his horizon, and consequently the heavenly bodies will appear to rise and set perpendicularly; and on account of the circles described by those bodies being cut at right angles by his horizon he is said to have a right position of the sphere. To an observer so situated all the stars will appear to rise and set once in twenty-four hours; and as the circles or parallels of motion

[1] From κολουρος mutilated, because that part of these circles which is near the south pole are never above our horizon.

of the Sun and stars are divided into two equal parts by his horizon, the days and nights will be equal to him throughout the whole year. In this position of the sphere the equinoctial or celestial equator becomes the prime vertical.

To an observer at either of the poles, the horizon and equinoctial coincide, and, consequently, the poles of the world are in his zenith and nadir; and since the Sun, Moon, stars, &c. will appear to him to move in circles parallel to the horizon, he is said to have a parallel position of the sphere. Those stars which are contained in his visible hemisphere will never set, and those in his invisible hemisphere will never rise; and as the Sun will be for one half of the year above and the other below the horizon, he will have but one day and night throughout the whole year.

The moon, also, for the same reason, during one half of her monthly revolution, will never rise above and during the other will never set below his horizon. It is obvious that in these and similar observations the refractive power of the atmosphere as explained in the sixth Lecture are not taken into account.

An observer between either of the poles and the equator is said to have an oblique position of the sphere, because the heavenly bodies seem to rise and set obliquely, and all the parallels in the sphere of the heavens have their planes oblique to the plane of his horizon. Since these celestial parallels become smaller as they recede from the equinoctial, towards either pole, it is plain that in an oblique sphere some of the parallels intersect the horizon at oblique angles, while some are entirely above, and some below the horizon. The largest parallel in the sphere of the heavens which appears entire above the horizon of any place, in-

cluding all those stars which never set to that place, is called the circle of perpetual apparition, and the largest parallel which never ascends above the horizon of any place, including all those stars which never rise, is called the circle of perpetual occultation. The stars comprehended within these circles (the magnitude of which varies with the distance of the place from the equator) are called Circumpolar Stars.

The circles of perpetual apparition and occultation of any place are as far from their respective poles as the place is from the equator; that is, their distance from the poles is equal to the latitude of the place; hence, to the inhabitants of London all those stars which lie within about 51° of the north pole never set, being within the circle of perpetual apparition of that place, and all those which lie within the same distance of the south pole never rise, being within the circle of perpetual occultation. The nearer, therefore, that any place is to one of the poles, or the greater the latitude of any place, the larger are the circles of perpetual apparition and occultation of that place, and consequently at the poles, or to those who have a parallel position of the sphere, the equinoctial is both the circle of perpetual apparition and occultation; for the equinoctial coinciding with the horizon, all the parallels on one side of it are entire above, and all those on the other side are entire below the horizon: thus to an inhabitant of the north pole all the northern parallels are entire above his horizon and never set, and all the southern parallels are entire below his horizon and never rise; while to an inhabitant of the south pole the reverse takes place, the southern parallels are above his horizon and never set, and the northern parallels being entire below his horizon never rise. In a right position of the sphere,

or to those who live on the equator, there can be no such thing as a circle of perpetual apparition or occultation, as no parallel appears entire above, or is hid entire below their horizon.

By reason of the Sun's apparent motion among the fixed stars, the rising and setting of these bodies have been observed in reference to that luminary, as well as in regard to the position of the sphere. They are considered as of three kinds, and distinguished by the names of Cosmical[1], Achronical[2], and Heliacal.[3] These are usually denominated the poetical risings and settings of the stars, being mostly taken notice of by the poets and historians. The knowledge which the ancients had of the motions of the heavenly bodies not being sufficient to adjust the true length of the year, the same day of the month did not always correspond with the same season of the year, and as the returns of the seasons depend upon the approach of the Sun to the tropical and equinoctial points, so they made use of these risings and settings to determine the commencement of the different seasons, and consequently the knowledge of these poetical risings and settings of the stars were among them held in great estimation.

Since the reformation of the calendar by Julius Cæsar, they have however fallen into disuse; the information which the moderns have acquired of the heavenly bodies rendering these, like many other observations highly esteemed by the ancients, in a great measure useless; and they are now chiefly employed in comparing, illustrating, and explaining passages otherwise obscure in the ancient writers.

1 From κοσμος the world.
2 From ακρον a point and νυξ night.
3 From ηλιος the Sun.

The cosmical rising of a star is when the star rises along with the Sun, the sunrise indicating, as it were, the morning of the world. If the star set at the time the Sun rises it is said to set cosmically.

A star or planet rising at sunset is said to rise acronycally, in which case the star or planet is sometimes said to be acronycal. The star or planet is said to set acronycally if it set with the Sun.

A star or planet is said to rise heliacally when, after having been in conjunction with the Sun, it rises in the morning so long before him as not to be rendered invisible by the brilliancy of his light, and to set heliacally when it sets so long after the Sun as not to be hidden by his beams.

The brightness of the Sun's light not only obscures and renders invisible those stars that are very near him, but extends its influence to those that are at a considerable distance from him; the distance of the stars, therefore, from the Sun at the time of their heliacal rising and setting, must vary according to their different degrees of magnitude and brilliancy; for it is evident that the brighter a star is the less will the Sun be depressed below the horizon, when that star first becomes visible. Stars of the first magnitude may be seen rising and setting when the Sun is 12° below the horizon; stars of the second magnitude, when the depression of the Sun is 13°, and so on, one additional degree of depression of the Sun being required for every decrease of magnitude in the stars.

The name of Dog-Days still given to about 39 days of the year seems to be a solitary vestige of this ancient method of reckoning, although every one at all conversant with the science of astronomy must be aware that what are now termed the *Dies*

Canicalares, or Canicular Days, have no connection with the heliacal rising of the dog-star. The "Dog-Days" begin in our almanacks on the 3d of July, or 12 days after the summer-solstice, and end the 11th of August, or 51 days after that period; their continuance, therefore, is 39 days. But Sirius rises heliacally at London on the 25th of August, or 13 days after the dog-days, and hence it appears that the heliacal rising of Sirius is quite unconnected in our latitude, at least, with what are called the Dog-Days. The ancients reckoned the beginning of the dog-days from the heliacal rising of Sirius. The Sothic year of the Egyptians was so called from its beginning on the first day of the month Thoth, or that on which Sirius or the Dog-Star rose heliacally. They are supposed to have commenced their year at this time, because the over-flowing of the Nile was annually announced by the heliacal rising of Sirius; and they even imagined this star to be the efficient cause of the over-flowing of the river, and from its colour at its first appearance prognosticated what kind of seasons were to ensue. If it rose of a fine golden colour, it was considered as a good omen, and a fruitful year was expected; if pale and dim. it was looked upon as portending scarcity. The name Sirius given to this star is supposed to have been derived from its rising heliacally shortly after the time that the Sun was in Leo, at which time he was adored by the Egyptians under the name of Sir or Osir, and the river Nile which, beyond Syene, is called Siris, received this name from its having attained its greatest elevation at this time. The annual re-appearance of this beautiful star, as it were to warn the people of Egypt of the approaching inundation, probably suggested the representation of

this constellation under the figure of a dog, an animal eminently distinguished for its fidelity and watchfulness.

Having contemplated the general appearances of the heavens as viewed from different parts of the Earth's surface, we shall be fully prepared to pursue with effect our investigations respecting the phenomena peculiar to the various bodies that compose our planetary system.

LECTURE VIII.

THE PHENOMENA OF THE SUN AS SEEN FROM THE EARTH. — OF THE APPARENT DIURNAL REVOLUTION OF THE SUN; — CAUSED BY THE ROTATION OF THE EARTH ON ITS AXIS. — THE VARIATION IN THE LENGTHS OF DAYS AND NIGHTS AND THE VICISSITUDES OF THE SEASONS EXPLAINED.

The Sun has already been described as the grand head of our system, and the centre round which the planets with their attendant satellites revolve. In contemplating, therefore, the phenomena presented to the observation of an inhabitant of our Earth, by the various bodies of which the planetary system consists, it will be proper to commence with those which seem to result from the apparent motions of this luminary.

The regular return of day, and night, or the alternate change from light to darkness, and from darkness to light, which takes place on our Globe, (and to most of the habitable parts of its surface, once in twenty-four hours,) together with the orderly succession of the seasons, are phenomena which cannot fail to have attracted the attention of mankind from the earliest period, and even long before Astronomy began to be cultivated as a science. During the progressive improvement which this science has undergone, the regular increase and decrease in the length of the days and nights, the vicissitudes of the seasons, and in fact every thing relating to, or in any way connected with, or necessary for obtaining an accurate divi-

sion of time, have been so minutely and thoroughly investigated, as to have enabled astronomers to furnish us with a Calendar, which, in its present improved state, may be considered a very near approximation to perfection.

It is not my intention, however, to enter upon a detail of the attempts that have been made to reform the Calendar, the chief object of which being to accommodate it to the periods of a solar and lunar revolution, could not with propriety be introduced in this place, my design in the present instance being to confine my observations to those phenomena which are exhibited by the Sun only, with respect to the Earth.

If we direct our view towards the east, a little before the rising of the Sun, we shall perceive a faint light gradually diffusing itself upon the horizon, each moment becoming more and more brilliant, and expanding through the heavens. The horizon now becomes tinged with the most vivid hues through one half of its extent, above the eastern verge of which, the Sun is seen majestically rising into view. After ascending above the horizon, his height and the splendour of his beams gradually increase, and he continues to ascend till he has attained the highest point of his path. His altitude now begins to diminish; he descends in a direction opposite to that in which he was observed to rise, and at length sinks below the western verge of the horizon, which exhibits similar appearances to those that were observed about the eastern side in the morning: this illumination, however, gradually becomes fainter, as the Sun's depression below the horizon increases, till having reached a certain point, it altogether disappears. After remaining invisible for some time, the Sun again re-appears near the same point where he formerly

rose into sight; he again performs his journey through the heavens, and again sinks below the horizon, and is lost to our view.

Now, since the Sun (as will be proved in its proper place) remains stationary in the centre of the planetary system, his apparent diurnal motion from east to west through the heavens must be caused by the rotation of the Earth on its axis from west to east, or in a contrary direction to that in which the Sun appears to move. When any place by the motion of the Earth on its axis is brought immediately under the Sun, the Sun is said to be in the meridian of that place, to which it is then noon or mid-day; and all those places which have their noon at the same time are said to be on the same meridian. The time which elapses between the arrival of the Sun at the meridian of any place, and his next subsequent arrival at the same meridian, is called a natural day; and this, were the Earth in other respects at rest or stationary with regard to the Sun, would be obviously equal to the time in which the Earth performs an exact revolution on its axis. The natural day is divided into twenty-four equal parts called hours, each of which is subdivided into sixty equal parts called minutes, and each minute into sixty equal parts called seconds; and, therefore, since the equator is divided into 360°, and the Earth turns round its axis once in 24 hours, there must be a revolution of 15° of the equator in one hour of time, or in other words, 15° of the equator will correspond to one hour of time, and consequently when it is noon at any one place, it will be one o'clock at all places 15° eastward of it, and 11 o'clock at all places 15° west of it, and so on.

If, therefore, we imagine twelve great circles, one of which is the meridian of a given place, to

intersect each other at the poles of the earth, and divide the equator into twenty-four equal parts, those are the hour-circles of that place, and are by the poles, themselves, divided into twenty-four semicircles.

I shall proceed to illustrate what has now been said by means of diagram 2., in which let S be the Sun, and H A O B be the Earth, of which the northern hemisphere only is visible in the figure; A the place of an observer on the equator; P the north pole, or northern extremity of the axis on which the Earth revolves, and the point wherein the hour circles or meridians intersect each other; the line A P being the meridian of the place A, to which an index is attached; and H O the horizon of the observer at A; the projections on either side of the Earth are called the morning and evening twilight. On the plane to which the Earth is fixed is a horary circle, the divisions of which coincide with the hour-circles drawn upon the figure representing the Earth.

This diagram being fixed on the machine, if the index be set to the midnight 12, or to that 12 which is most distant from the Sun, then, to an observer at A, the Sun is evidently invisible. The Earth being now made to revolve on its axis in the order of the figures on the horary circle, till the index points to about twelve minutes before five o'clock, the Sun being about 18° below the horizon, the morning twilight commences and ends when the index points to six o'clock A. M., at which time the Sun will become visible to the spectator at A, and will appear to rise or ascend above his horizon. As the Earth's motion continues, the height of the Sun above the horizon gradually increases, till the index points to twelve o'clock at noon, when the Sun will appear to have attained his greatest eleva-

tion, or to have arrived at the highest point of his apparent path through the heavens. The motion of the Earth being continued, the height of the Sun gradually decreases, and when the index points to six P. M., or when it is six o'clock in the evening to the observer at A, the Sun appears to set or to descend below his horizon. The evening twilight now commences, and ends at about twelve minutes past six, when the Sun will have sunk about 18° below the horizon: from this time the spectator is involved in total darkness till about twelve minutes before five in the morning, when the twilight again begins and ushers in the succeeding day.

It has already been observed that the hour-circles are divided by the poles of the Earth into 24 semicircles, which are the meridians of the places through which they pass, and that these semicircles intersect the equator in 24 points, equally distant one from another, and consequently divide it into twenty-four equal parts, each of which contains 15°, and corresponds to an hour of time. A bare view of the figure is sufficient to corroborate these observations, and also to show that all those persons whose meridian is 15° east of any particular place have the noon, and consequently every other hour of their natural day, an hour sooner than those at the given place; while those persons whose meridian is 15° west from that place have their noon, and every other hour of their natural day, one hour later. Hence it is that a person setting out from any place and sailing eastward quite round the globe will reckon one more day to have passed during the time of his voyage than they do who have remained all that time at the place whence he set out, and consequently at his return thither will count the day of the week and month one day forwarder than the inhabitants of that place; thus

their Monday will by him be accounted Tuesday, their Tuesday will be his Wednesday, &c.: in like manner, a day which they would reckon the first of the month, he will consider the second of the same month; what to them will be the second of the month, will be his third, and so on. If, instead of sailing eastward, his voyage be performed in a contrary direction, that is, if he sail round the Globe westward, he will appear to have lost a day, and will, upon his return, reckon his time one day behind those who dwell at the place from which he set out; thus their Tuesday will by him be accounted Monday: their Wednesday will be his Tuesday, and so on. By referring again to the diagram, the whole of this will be rendered perfectly intelligible. Let A be the place from which a person sets out to circumnavigate the Globe in an easterly direction, or according to the order of the figures on the horary circle, when he has got 15° to the east of that place, it will be noon with him one hour sooner than with those who live at A, for by revolving the Earth on its axis, it evidently appears that the meridian at which he has arrived comes to the 12 marked noon in the horary circle, or which is the same thing, comes under the Sun one hour sooner than the meridian he has left; when he arrives at the next meridian, he will have his noon one hour sooner still, or two hours before those who live at A; and by thus continuing to gain an hour every 15° he advances eastwards, it is obvious that when he arrives at the place A from which he set out, having passed over twenty-four such spaces of 15° each, he will have gained twenty-four hours upon those who live at that place; and, consequently, though he will have his noon at the same time with them, he will have advanced a a day in his reckoning in the manner already

described. Now let us suppose a person to set out from the same place westward; in this case it is evident that for every 15° he travels he loses one hour in coming to the meridian, or comes to the meridian one hour later than he would have done had he remained at A; and, therefore, by travelling through the whole of the 360°, into which the equator is divided, he must evidenly lose twenty-four hours, or one natural day, and will consequently at his return consider that day Monday, which those who reside at A reckon Tuesday, that day Tuesday which they call Wednesday, and so on.

From what has now been said, it is manifest that if two persons start from the same place at the same time, but in contrary directions, the one travelling eastward and the other westward, and each goes completely round the terraqueous globe, although they should both arrive again at the very same hour at the place from which they set out, having each completed his journey in the same time, yet they will disagree two whole days in their reckoning; if, therefore, according to the one of those travellers, their return be on a Monday, the other will assert it to be on a Wednesday, while those who live at the place itself will agree with neither, but if referred to to settle the dispute, will tell them that they have arrived on a Tuesday.

Nor is it necessary, in order to produce the gain or loss of a day, that the voyage should be made upon the equator, or even on any of the parallels; it is sufficient for the purpose that the several meridians be passed through eastward or westward. The time also taken up in the voyage is equally unimportant; the gain or loss of the day being the same, whether it be performed in twenty-four years, or in as many hours; to prove

which, let us suppose a traveller to change his meridian 15° every year, it is evident that if he travel eastward he will gain, and if westward he will lose, one hour that year, and consequently, by continuing to travel in the same direction, and at the same rate, he will take twenty-four years to pass through the twenty-four spaces of 15° each, into which the equator and every parallel is divided, and to arrive again at the meridian from which he set out: yet in that time he has gained or lost no more than twenty-four hours, or one natural day. Now, let us suppose a person to travel eastward round the Earth, at the rate of 15° every hour, and that he leaves any place, as A, at noon, or twelve o'clock, on a Monday. In one hour's time, he having got 15° east of the place A, and the place itself having been carried 15° from the Sun, by the Earth's rotation on its axis, it is evident that he will be 30° from the Sun; in another hour, or when he has got 30° from the place A, he will be 60° from the Sun, and so on; getting every hour 30° farther from the Sun, so that at the end of six hours he will be 180° from the Sun, and will consequently have midnight when it is only six o'clock in the evening at the place from which he set out; at the end of twelve hours he will have got half way round the Earth, and the Earth having in the same time performed half a rotation on its axis, the Sun will again be upon his meridian, and he will, therefore, reckon it mid-day, or noon, on Tuesday, when it is only midnight on on the Monday to those who live at A; during the next twelve hours the same phenomena will be repeated; he will again experience the varieties of day and night; and though he will obviously arrive again at A at twelve o'clock on Tuesday, he will consider it Wednesday, reckoning his time by the

return of the Sun to his meridian. If, on the other hand, we suppose him to travel with the same velocity westward, as his motion will then be in the same direction as the apparent motion of the Sun, and at the same rate, he will obviously have the Sun on his meridian during his whole journey, and, consequently, experiencing no succession of day and night, nor even any change of time as shown by the Sun, he must, on his return to the place whence he set out, have lost a day, or be one day behind the inhabitants of that place in his reckoning.

It is evident that could such instances occur as those last mentioned, the cause of the loss or gain of a day in going round the globe could not long remain a secret; but as, in the course of long voyages, this phenomenon takes place imperceptibly, it for a long while remained a matter of surprise to seamen and others in what manner it was effected.

The change which takes place in the length of the days and nights, and the regular succession of the seasons to each other throughout the year, would naturally lead to a more minute investigation of the apparent motions of that luminary, upon the position of which, with regard to our Earth, the varieties of the one, and the vicissitudes of the other, so obviously depend; nor could this investigation be long continued, without leading to a discovery of the apparent annual motion of the Sun through the heavens, in a contrary direction to his diurnal motion; and although, on account of the great splendour of the Sun's rays, his revolution among the stars is not quite so easily detected as that of the Moon, yet it may be ascertained in the following manner: take notice, at any season of the year, of some bright star,

which sets about an hour after the Sun, and as nearly as possible on the same point of the horizon; each succeeding evening the distance between the Sun and star will appear to diminish, and they will be seen to approach nearer and nearer to each other, till at length the star will be lost in the brilliancy of the solar rays. About a fortnight after losing the star at night, it will be seen on the other side of the Sun, rising before him in the morning; the distance between the Sun and star will daily increase about 1°, and in the same month of the following year, they will come into nearly the same situation with regard to one another in which they were first observed.

If, instead of confining our observations to one particular star, we notice just after sunset two or three stars nearly east of each other, we shall find that these stars are successively lost in the rays of the Sun; others will succeed to them, and, like them, be regularly enveloped in his light and lost to our view, till at length, by continuing our observations, we shall find that the Sun has made a complete tour of the heavens.

If, moreover, we carefully observe the points of the horizon upon which the Sun rises and sets at different times of the year, we shall find that they are not always the same: thus, on the 21st of March the Sun rises due east and sets due west; from this time the points of rising and setting advance towards the north till about midsummer, when they become stationary for a few days, after which they begin to recede towards the south, and about the 21st of September they are again in the same situation as they were about the 21st of March: from this time the Sun continues to rise and set more and more southerly till midwinter, when it again appears to rise and set for several

days together upon the same points of the horizon; it then gradually rises and sets more northerly till the 21st of March, when the Sun having returned to the point from which it set out, the same phenomena again take place.

This change in the rising and setting points, clearly demonstrates that the apparent annual motion of the Sun is not performed in the equinoctial or the celestial equator, for in that case he would always rise due east, and set due west; but that it describes a circle, one half of which is north and the other south, of the equinoctial, and consequently the Sun, during one half the year, has north, and during the other, south declination. This may be further proved, and the Sun's declination north and south of the equinoctial ascertained, by observing his meridian altitude at any place: the difference between this and the altitude of the equinoctial at that place is the declination of the Sun for the day on which the observation is made, and is north or south as the Sun is north or south of the equinoctial. The altitude of the equinoctial, or its height above the horizon of any place, is always known, being equal to the complement of the latitude of that place, or what the latitude wants of 90°; and when the altitude of the Sun is the same as that of the equinoctial it is evident that he can have no declination, being situated on that circle.

By this method, which is that by which the Chaldean astronomers first ascertained that the circle described by the Sun in his apparent annual revolution round the Earth was inclined to the equinoctial, it will be found that the greatest declination of the Sun, or its utmost limits north and south of the equinoctial, is something less than 23° 28'. The obliquity of the ecliptic is not per-

manent, but is perpetually diminishing and approaching nearer to a parallelism with the equator, at the rate of about half a second in a year.

Having thus ascertained that the Sun has an apparent annual motion from west to east round the heavens, and having also determined the extent of this motion north and south of the equinoctial, it will be proper, in the next place, to consider by what means the apparent path of the Sun through the heavens may be most easily traced: this may be effected in the following manner:—

It has been already observed, that from the meridian altitude of the Sun on any day (the altitude of the equinoctial being known) his declination for that day may be found, the converse of which is also true, viz. that from the declination of the Sun his meridian altitude may be obtained; for if, when the declination is north, we add to it the altitude of the equinoctial, the sum will be the altitude sought; and if, when the declination is south, we subtract it from the altitude of the equinoctial, the remainder is the Sun's meridian altitude. It is obvious that for places in south latitude the operation must be reversed. These things being premised, begin at any season to mark the stars that culminate [1], or come upon the meridian at midnight; as the Sun will be upon the same meridian with these stars six months after the time of the observation, take out from White's Ephemeris, or any convenient table for the purpose, the declination of the Sun for that day, and by the method already described find the Sun's meridian altitude, which being set off amongst those stars, the Sun's place will be readily found; and

[1] From *culmen* the top or highest point.

by thus making similar observations throughout the year, the path which the Sun describes by his apparent annual motion through the heavens will be easily traced out. This great circle is called the Ecliptic, and is, in fact, the heliocentric circle of the Earth, or the circle marked out among the stars, by extending the plane which passes through the orbit of our own Earth; for this apparent motion of the Sun from west to east arises (as will be hereafter demonstrated in proving the truth of the Copernican system) from the annual motion of the Earth round the Sun in the same direction, and in the same plane.

If, therefore, the Earth is in any point of its orbit the Sun will always appear to be in the opposite point of the heavens; and as the Earth moves towards the east, the Sun will appear to move in the opposite direction, and, consequently, when the Earth has completed one revolution in its orbit, the Sun will appear to have completed one revolution in the ecliptic; and since this circle is found to be inclined to the equinoctial at an angle of 23° 28′, it is evident that the Earth's equator is inclined 23° 28′ to its annual orbit, or which is the same thing, that the axis of the Earth is inclined 66° 32′ to the plane of its orbit, or declined 23° 28′ from the perpendicular. The two opposite points in which the equinoctial cuts the ecliptic are called the Equinoxes, because the Sun, when in these points describing by his diurnal motion a circle coincident with the terrestrial equator, makes the day equal to the night in every part of the Earth. They are called the Vernal[1] and Autumnal Equinoxes, to denote the seasons of the year in which they take place.

[1] From *vernus* belonging to the spring.

Those parallels which the Sun describes when at its greatest distance from the equinoctial, *i. e.* when he has 23° 28′ north, and 23° 28′ south declination, are called the Tropics.[1] That tropic which is north of the equinoctial is called the Tropic of Cancer, because it is described by the Sun when he enters the sign Cancer; and that which is south of the equinoctial is called the Tropic of Capricorn, because the Sun describes this parallel when he enters the sign Capricorn. When the Sun is in either of these points he does not change his declination for several days together, hence these are called the Solsticial Points or Solstices[2], that being denominated the Summer solstice in which the Sun is situated on our longest day, and that the Winter solstice which the Sun occupies on the shortest day. It is evident that the terms Spring, Autumn, Summer, and Winter, applied to the equinoxes and solstices, together with many other expressions made use of by astronomers, relate to persons and places situated on the north side of the equator: to account for which, it is to be observed, that all the works we have upon this science were written by persons inhabiting the northern parts of the Earth, who very naturally made use of such terms as were adapted to their own situation, and to the situation of those for whose use their works were principally intended. A circle parallel to the equinoctial, 23° 28′ distant from the north pole, is called the Arctic[3] Circle, and a similar one at the same dis-

[1] From τρεπω to turn back.

[2] From *solis stationes* the stations of the Sun, or from *sol* the Sun, and *stare* to stand.

[3] From αρκτος a bear, the constellation so called being near the north pole in the heavens.

tance from the south pole, the Antarctic[1] Circle; a line or circle drawn through any place parallel to the equator is called the Parallel of that place.

The variation in the meridian altitude of the Sun is attended with a corresponding change in the length of the artificial day, or in the continuance of the Sun above the horizon. On the 20th of March he rises at six in the morning, ascends in an oblique direction to the meridian, and as gradually descends to the western verge of the horizon, which he reaches at six in the evening, after having continued for twelve hours to enliven us with his presence. The length of the day continues to increase with the increasing altitude of the Sun till the 21st of June, when he remains something more than 16 hours above our horizon without setting. The altitude of the Sun having now reached its maximum, the length of the day begins to decrease, and about the 23d of September is exactly the same as it was on the 20th of March. The days continue to diminish in length, with the decreasing altitude of the noonday Sun, till the 21st of December, when his short continuance above our horizon, which does not exceed eight hours, and the obliquity of his rays, bring on the dreariness of Winter. To understand this, let A B C D, fig. 13., be the Earth, in four different parts of her orbit; *n s* its axis inclined 66° 32′ to the plane of its orbit, and keeping always parallel to itself; *n* its north, and *s* its south pole. Let ♋ be the tropic of Cancer, ♑ the tropic of Capricorn, *a* the arctic circle, *b* the antarctic circle, and *e* the equator. When the Earth is in the position A, which it has on the 21st of June, its north

[1] From αντι opposite to, and αρκτος a bear.

pole *n* inclines towards the Sun S, by which inclination of the Earth's axis the Sun, at this season of the year, is 23° 28′ above the terrestrial equator; and as he enlightens only one hemisphere, or one half of the Earth at a time, the north pole *n* will be illuminated, and this illumination will extend 23° 28′ beyond the pole, to the most distant part of the arctic circle. While, therefore, the Earth revolves upon its axis *n s*, that part of the Earth included within the arctic circle will be enlightened during the whole diurnal rotation of the Earth and the inhabitants will enjoy perpetual day. For the same reason that part of the Earth comprehended within the antarctic circle will be involved in total darkness during the Earth's rotation. Those regions of the Earth which lie between the arctic circle and the equator will, during a part of the Earth's diurnal revolution, be carried into the dark hemisphere, but as they will continue during a longer period in the enlightened hemisphere, the day will be longer than the night. At the equator the day and night will be exactly of an equal length; and between the equator and the antarctic circle the night will be longer than the day. When the Earth is at D, on the 21st of December, the north pole declining from the Sun, the reverse of all this takes place, the whole of the arctic circle is involved in total darkness, while the antarctic circle is entirely illuminated: those places which lie between the arctic circle and the equator have the night longer than the day, while those which lie between the equator and the antarctic circle have the day longer than the night. On the equator the days and nights are of an equal length all the year round. When the Earth is at B or D, its axis inclines neither to nor from the Sun, which, being vertical to the equator, makes equal day and

night at all places on the Earth's surface. I shall now proceed to exhibit these phenomena, together with all the intermediate situations of the Earth in its annual motion round the Sun, in a diagram, by means of which, the whole theory of the seasons will be easily understood. Let S, diagram 3., represent the Sun, and E the Earth, having its pole *p* declined 23° 28′ from the perpendicular, *e q* is the equator, *t* ♋ the tropic of Cancer, *t* ♑ the tropic of Capricon, and L London, the parallel of which is represented by the dotted circle passing through the point L; the silk string or thread represents the terminator or boundary of light and darkness, in all situations of the Earth during its revolution round the Sun, while the index I points to the Sun's place in the ecliptic. Put the diagram on the machine in the usual manner by slipping the Sun over the central point, and screwing on the nut; then having brought the Earth to the first point of Libra, rectify it by bringing the pole into such a position that the meridian of London may be parallel to the dotted lines on the machine, and the pole directed to the north or upper part of it. The Earth is now in the position it has on the 20th of March, at which time the tropic of Cancer, the parallel of London, and the artic circle, are all equally cut by the boundary of light and darkness; and hence the equality in regard to the length of day and night which at this time prevails in all parts of the world except at the poles, it being the beginning of day at the north pole, which is just coming into light, and the end of day at the south pole, which is just going into darkness. The Earth is in the beginning of Libra, and the Sun, as is shown by the index I, enters the sign Aries on this day, which is the vernal equinox, the first day of spring, and the commencement of the astronomical year.

The Earth moving in the ecliptic, according to the order of the signs, enters Scorpio on the 20th of April, as shown by the index; and by carefully preserving the parallelism of the Earth's axis (which may be regulated by means of the dotted lines before mentioned) it will be seen that the north pole comes more into the light, the days increasing as the nights decrease in length, in the northern hemisphere, as is shown by the silk line which denotes the boundary of light and darkness, and which has now receded considerably from the pole. The Sun on this day enters the sign Taurus, which is the second of the spring signs. — Continuing the Earth's motion in the ecliptic, it will be found by the index to enter the sign Sagittarius on the 21st of May; the north pole is considerably more advanced into the light; the days have proportionably increased in length in the northern regions; and at London the day is at this time almost twice as long as the night. The Sun as seen from the Earth passes on this day from Taurus to Gemini, which is the last of the spring signs: — on the 21st of June, being the first day of Summer and the longest day in the northern hemisphere, the Earth enters the sign Capricon: the north pole now has its greatest inclination to the Sun, the light of which, as shown by the boundary of light and darkness, extends to the utmost verge of the arctic circle, the whole of which is included in the enlightened hemisphere of the Earth, and enjoys at this season constant day during the complete revolution of the Earth on its axis. On the parallel of London the day commences a quarter before four in the morning, and terminates at a quarter past eight in the evening, making this day of 16½ hours' duration to the inhabitants of London, and to all those who reside on the same parallel. The Sun

also having now attained his greatest north declination enters the sign Cancer in the ecliptic, being vertical to the tropic of that name.—The Earth pursuing its annual motion in its orbit enters Aquarius on the 23d of July; and as its axis always continues parallel to itself, the boundary of light and darkness begins to approach nearer to the pole, and the length of the day, which had arrived at its maximum, begins gradually to decrease, the Sun at this time entering Leo, which is the second of the summer signs.—The Earth by its progressive motion has now arrived at the sign Pisces, which it enters on the 23d of August, the Sun appearing at the same time to have made his transit from Leo into Virgo, which is the last of the summer signs.—From Pisces, the Earth arrives at Aries, which it enters on the 23d of September, at which time the boundary of light and darkness again passes through the pole: the parallels are again equally divided by it, and the days and nights are once more of an equal length on all parts of the Earth except at the poles; the north pole being about to sink into nocturnal darkness, while the south pole has the day just commencing. The Sun on this day enters the sign Libra, which is the first of the autumnal signs, and is again vertical to the terrestrial equator.—On the 23d of October the Earth again changes its sign, and quitting Aries, enters Taurus, the days visibly decreasing in length in the northern hemisphere of the Earth; while the Sun appears to enter the second autumnal sign, or Scorpio.—Having passed through Taurus, the Earth enters the sign Gemini on the 22d of November; the boundary of light and darkness is now at a considerable distance from the north pole, which declines from the Sun; the parallels of latitude also in the northern hemisphere extend but a little way

into the enlightened part of that hemisphere, while the decrease in the length of the days, and the oblique direction in which the Sun's rays descend upon these regions of the Earth, infallibly point out the near approach of Winter. The Sun as seen from the Earth on this day enters Sagittarius the last of the autumnal signs.—On the 21st of December, which is the period of the Winter solstice, the Earth enters the sign Cancer. At this time the southern hemisphere enjoys all those advantages with which the northern hemisphere was favoured on the 21st of June, while the northern hemisphere has to undergo, in its turn, the inconveniences of short dull days and long and dreary nights, the Sun being vertical to the tropic of Capricorn, which sign he enters on this day. This is the first of the Winter signs.—From the sign Cancer, the Earth passes to Leo on the 20th of January, the days increasing gradually in length in the northern hemisphere, in the same manner as they decreased about the 22d of July. The Sun on this day passes into Aquarius, which is the second of the Winter signs.—The Earth enters Virgo about the 19th of February, when the boundary of light and darkness again approaches the pole, and the days continue to increase in length in the northern hemisphere, as the Earth by passing from Leo to Virgo causes an apparent transit of the Sun from Aquarius to Pisces, the last of the Winter signs.—After passing through the sign Virgo, the Earth again enters Libra, causing an apparent motion of the Sun into Aries: the severity of Winter once more yields to the genial influence of a vernal Sun, and the phenomena we have been describing are again repeated in the same order.

It need scarcely be remarked, that in the preceding illustration of the seasons the phenomena in

the northern hemisphere have been principally regarded. The hints which have been occasionally dropped in the course of this explanation are sufficient to show that in the southern hemisphere the phenomena throughout are directly the reverse.

The difference in the meridian altitude of the Sun, and the length of time he continues above the horizon, produce a peculiar temperature by which each particular season is distinguished. In Winter very little warmth is derived from the Sun on account of the oblique direction in which his rays strike the earth, and his short continuance above the horizon; the little heat which is thus produced being entirely dissipated by the succeeding long nights: whereas in Summer the Sun's rays falling almost perpendicularly, and the very great proportion of the natural day, during which the Sun lingers above the horizon, generate a degree of heat which his short absence can scarcely diminish.

It may be very naturally asked, why, if the increase of heat in the Summer season be produced in the manner just described, we have not the hottest weather at the time of the Summer solstice, when both the causes operating most forcibly, it might reasonably be expected that the greatest effect should be produced? Yet experience convinces us this is not the case, and that the heat is generally the greatest about the latter end of July and the beginning of August, when the Sun is removed from the tropic a whole sign. In answer to this it is to be observed, that this excess of heat is an effect produced by the long continued action of the solar rays, by which more heat being imparted by day, even for some time before the Sun enters the tropic, than is lost during the night, there must

be an accumulation or increase of heat, which will continue to receive further augmentation, not only till the Sun has entered, but even for some time after he has left the tropic. When, however, the continuance of the Sun above the horizon, or the length of the day has so far decreased, that more heat is lost during the night than what is communicated by day, the Earth gradually cools. It is evident, therefore, that the greatest heat of summer must necessarily take place considerably after the Sun has left the solstice. In like manner the rigour of winter is usually found to be most predominant about the end of January and the beginning of February, the cause of which will be easily understood from the foregoing remarks.

I shall conclude this lecture by briefly observing, that besides the division of the signs into Spring, Summer, Autumn, and Winter, they are also divided into northern and southern; the former consisting of all those which are north of the equinoctial, and the latter, of those which are south of it: they are likewise distinguished by the terms ascending and descending; the ascending signs commencing with Capricornus, and ending with Gemini; and the descending signs beginning with Cancer, and ending with Sagittarius.

LECTURE IX.

THE PHENOMENA OF THE SUN AS SEEN FROM THE EARTH CONTINUED. — OF THE INEQUALITY OF THE SUN'S APPARENT ANNUAL MOTION, AND THE CHANGE IN HIS APPARENT DIAMETER. — THE MOTION OF A PLANET IN AN ELLIPTIC ORBIT EXPLAINED.

In pursuing our investigations relative to the phenomena exhibited by the Sun to a spectator placed on the surface of our own Earth, and in accounting for those phenomena, the apparent diurnal and annual motions of that luminary have been fully described, the succession of day and night explained, and the regular returns of the seasons completely illustrated; the day also of his entrance into each of the signs of the fixed zodiac of Hipparchus have been particularly pointed out. In contemplating these phenomena, no notice has hitherto been taken of any inequalities in the annual motion of the Sun, nor of any variation in the apparent magnitude of that luminary. If, however, we carefully note the time at which the Sun is in the equinoxes, we shall find that he is about eight days longer on the north side of the equator than on the south of it, or that the days of the equinoxes divide the year into two unequal parts; in other words, that the Sun appears to take about eight days more to move from the vernal to the autumnal equinox than he does to pass from the autumnal to the vernal. Now as the signs of the zodiac consist each of 30°, and the number of signs passed through by the Sun in both cases is alike, this observed difference would naturally lead us to

conclude that the Sun's apparent motion is not equable, but that he must move faster at one time of the year than at another. This conclusion is confirmed by observation; and it is found that his motion is most rapid about midwinter, and slowest about midsummer; the velocity of his motion gradually decreasing from the beginning of January to the beginning of July, and as gradually increasing from the beginning of July to the end of December. If by means of a micrometer we measure the diameter of the Sun at different times of the year, it will be found that an exact coincidence at all times exists between his apparent diameter and the velocity of his motion: when the velocity of the Sun is a maximum, his apparent diameter is a maximum also; as his velocity decreases, so does his diameter likewise: when his velocity is a minimum, so is also his apparent diameter; and as his velocity increases, his apparent diameter increases at the same time. To prove this, let the apparent diameter of the Sun on the first day of every month throughout any year be compared with his hourly motion in the ecliptic on the same days. If the experiment be made during the ensuing year, 1826, the result will be as follows: on the 1st of January the Sun's apparent diameter will be 32 minutes, 35·6 seconds, and his apparent motion in the ecliptic at the rate of 2 minutes, 32·9 seconds of a degree per hour; on the 1st of February his apparent diameter will be 32 minutes, 30·6 seconds, and his hourly motion 2 minutes, 32·2 seconds; on the 1st of March the Sun's apparent diameter will be 32 minutes, 19·2 seconds, and his hourly motion 2 minutes, 30·4 seconds; on the 1st of April the apparent diameter of the Sun will be 32 minutes, 2·6 seconds, and his hourly motion 2 minutes, 27·8 seconds; on the 1st of May his apparent diameter will be 31 minutes, 46·8 seconds, and his

hourly motion, 2 minutes, 25·4 seconds; on the 1st of June, his apparent diameter will be 31 minutes, 35·2 seconds, and his hourly motion, 2 minutes, 23·6 seconds; and on the 1st of July, the Sun's apparent diameter will be 31 minutes, 31 seconds; and his hourly motion, 2 minutes, 23 seconds. It is obvious, therefore, that during the foregoing months, the apparent diameter of the Sun, and the velocity of his apparent hourly motion, have both gradually decreased; from this time they will be found to increase through the six following months; thus, on the 1st of August, the Sun's apparent diameter will be 31 minutes, 35 seconds, and his hourly motion, 2 minutes, 23·6 seconds; on the 1st of September, his apparent diameter will be 31 minutes, 46·4 seconds, and his hourly motion, 2 minutes, 25·3 seconds; on the 1st of October, his apparent diameter will be 32 minutes, 2 seconds, and his hourly motion, 2 minutes, 27·7 seconds; on the 1st of November, his apparent diameter will be 32 minutes, 18·8 seconds, and his hourly motion, 2 minutes, 30·3 seconds; on the 1st of December, the Sun's apparent diameter will be 32 minutes, 31 seconds, and his hourly motion 2 minutes, 32·2 seconds; the apparent diameter of the Sun and the velocity with which he appears to move eastward in the ecliptic will continue to increase till the 1st of January following, when, being once more the greatest possible, they again begin to decrease.

Now, the angle subtended by any body being always inversely proportional to the distance of the body from the observer, these varieties in the apparent diameter of the Sun evidently arise from a constant variation in the distance between the Sun and Earth, and show that the Earth is nearer to the Sun at one time of the year than at another;

and since it has already been declared, and will hereafter be proved, that the apparent annual motion of the Sun is caused by the revolution of the Earth in its orbit, these changes in his apparent magnitude, which are regularly repeated every year, prove that the Earth revolves in an elliptical orbit round the Sun, placed in one of its foci.

The elliptical form of its orbit, and the inequality of its motion, are not phenomena peculiar to our Earth only, but common to all the planets of the system, whether primary or secondary, and in performing their several revolutions round their respective centres, they all observe one general law; namely, that a line drawn from the planet to the centre round which it revolves, passes over equal areas upon the plane of its orbit in equal times, and this line is called the radius vector.

In order to render this important subject perfectly understood, I shall proceed to illustrate it by diagram 4: in which let S represent the Sun, and E the Earth revolving in an elliptic orbit; the line *r v* (supposed to be continued through the groove *x*), which connects the centres of the Sun and Earth, is called the radius vector; this line shows the distance between the two bodies, and gradually increases and decreases in length according to the situation of the Earth in its motion round the Sun. The elliptical groove A B C D E F G H I K L M N O P Q, is the orbit in which the Earth revolves, the plane of which is divided into mixed triangles of equal superficial contents, by the lines drawn from the centre of the Sun, or rather from the focus in which he is placed, to the points A B C D, &c. of the orbit; these lines may also be called radii vectores, and will evidently coincide with the moveable radius vector when the Earth arrives at the points A, B, C, D, &c. of its orbit.

In placing this diagram on the machine, it is to be observed, that after fixing it in the usual manner on the central point, that point must be made to pass through the groove x, the Sun S is then to be slipped on, and the nut screwed down, the line of the apsides upon the diagram, being made to coincide with the line of the same name on the machine.

Now, it has been already observed,* that the motion of a planet revolving in an elliptic orbit is such, that the radius vector passes over equal areas in equal times, for which reason the elliptical figure in the diagram, which represents the plane of the Earth's orbit, is divided into a series of mixed triangles, the areas of which are equal to each other. The sides of each of these triangles consist of two straight lines, and an arc of the ellipse, and it is obvious that, in order to make the areas equal, the shorter the straight lines of any triangle are, the longer must be the arc, and *vice versâ*. Now the straight lines, or radii vectores must be shorter the nearer to the perihelion, and longer the nearer to the aphelion, and consequently the arcs described by the Earth in its orbit, in a given time, are louger the nearer the Earth is to its perihelion, and shorter the nearer it is to its aphelion; but as to describe a longer arc in the same time as a shorter one, must evidently require a greater velocity in the moving body, it will be seen, by making the Earth to pass through the spaces A B, B C, C D, &c. in equal times completely through its orbit, that while the Earth is going from A or the aphelion to I or the perihelion, its motion is constantly accelerated, and in going through the other half of its orbit, or from the perihelion to the aphelion, it is as regularly retarded.

While the Earth is made to revolve in its orbit in the manner here described, the index points out the apparent motion of the Sun in the ecliptic, which has already been shewn to result from the Earth's motion round that luminary. By noticing, therefore, the spaces passed over by the index, it will be found, that were the Earth's orbit as elliptical as the figure by which it is here represented, the Sun would appear to pass through no less than one whole sign, and 15° of another, in one part of its revolution, in the same space of time in which it would, at another part of its revolution, describe an arc of only about 10° of the ecliptic: or, which is the same thing, that the velocity of the Earth's motion while describing the arcs H I, I K, of its orbit, would be about four and a half times as great as it would be while describing the arcs Q A, A B. The ellipse here described is, however, far more eccentric than the orbit of the Earth, or of any other primary planet, all of whose orbits are so nearly circular, that it would be impossible in a figure of this magnitude, if drawn in true proportion to the orbit of either of them, to make any sensible difference between the arcs of the triangles into which it is requisite to divide the figure in order to give the required illustration.

The orbit of the Earth being so nearly circular, the difference of heat derived from the Sun when the Earth is at its greatest and least distance from him will be very trifling: and as the Earth happens to be in its perihelion in the beginning of January, and in its aphelion in the beginning of July, the only effect we find to result from our proximity to the Sun in winter, and our increased distance from him in summer, is a trifling diminution of the extreme frigidity of the former season, and the intense heat of the latter; both which

have already been shown to arise from the difference in the meridian altitudes of the Sun, (whereby his rays fall upon the Earth with a greater or less degree of obliquity,) and the time of his continuance above the horizon.

For the discovery of the elliptical form of the planetary orbits, and the law according to which the revolutions of the several planets in their respective orbits are performed, we are indebted to the singular sagacity, and indefatigable industry of Kepler, who likewise ascertained another important fact relative to these bodies; for, having observed that the periodic times of the planets increased with their mean distances from the Sun, he was led to suppose that some analogy ought to exist between them; and he at length succeeded in discovering that the squares of the periodic times were as the cubes of their transverse axis, or as the cubes of their mean distances from the Sun; for, by the nature of an ellipse, the mean distance of a planet revolving in an elliptic orbit is equal to one-half of the transverse axis of the orbit, and since the halves, are as their wholes, the ratio is the same with regard to both. This discovery, which was the result of 17 years laborious investigation, was made on the 15th of May, 1618.

These important facts, usually denominated Kepler's Laws, may be considered the foundation of Physical Astronomy, and were chiefly deduced by him from the numerous observations of the celebrated Danish astronomer Tycho Brahe. These laws not only apply to the orbits of the planets and satellites, but to those of all the comets which have been accurately observed. They are usually expressed as follows:

1. All the planets revolve round the Sun in such a manner, that the radius vector, or line drawn

from the Sun to the planet, describes equal areas in equal times.

2. Each planet describes an ellipse, having the the Sun in one of the foci.

3. The squares of the periodic times of the planets have the same proportion to one another as the cubes of their mean distances from the Sun.

These laws of the planetary motions, discovered by Kepler, were afterwards fully demonstrated and explained by Sir Isaac Newton upon the principles of Universal Gravitation, and the uniform projectile motion of bodies in straight lines.

Although it is by no means my intention to follow that sublime genius through all his geometrical demonstrations of the accordance of these laws with the phenomena to which they refer, yet I shall nevertheless endeavour to give a plain and familiar explanation of the manner in which a planet circulates round the Sun, continually approaching towards him during one part of its revolution, and receding from him at another, without ever actually falling to that luminary, or departing so far from him as to get beyond the sphere of his influence.

It has been observed, in a former lecture, as an established law of nature, that all motion is of itself rectilinear, and that a body once put in motion would for ever continue to move forward in the same right line, unless it were acted upon by some other force in a different direction, or if it were at rest, it would for ever so continue, unless some active cause produced a change.

Suppose a body at A, fig. 14., struck in the direction A B, with such a force as would cause it to describe the line A B in a given particle of time, at A let it also receive an impulse in the direction A C, which would cause it in the same time to describe the line A C = A B. The body being acted upon at the sa instant by two forces in

different directions will, by the combination of these forces, take an intermediate course, and describe the diagonal A D, and the two forces being equal, the point D, at which the body will have arrived at the expiration of the particle of time, will be exactly as far from the places B and C, to which the acting forces respectively tended to carry it, as the point A, where the body was at the time of receiving these impulses. But if, as in fig. 15., the impulses A B and A C be unequal, then the body in the same particle of time will describe the line A D, and when at D, will be at the same distance from the more remote place of tendency B as it was from the nearer C; and at the same distance from the nearer place of tendency C, as it was from the more distant one B, at the time of its setting out from A. If the force A C, instead of acting by a single impulse, had been a constantly accelerating force, the line A D would have been a curve of greater or less curvature, according to the nature of the accelerating force.

Now, the universal power of gravity or attraction, is a constantly accelerating force, the law of which has been already explained; if, therefore, a body gravitating towards a centre, receive a projectile force in a direction not passing through that centre, it will, by its compound motion, describe a curve in every point of which it will have a tendency to fly off from the axis of its motion in a tangent to the periphery of the curve; and is only prevented from so doing by the deflecting force. The force by which the body endeavours to fly off in a right line, is called the centrifugal force, and that by which it is impelled towards the centre is called the centripetal[1] force. These two forces, by the joint action

[1] From *centrum*, a centre, and *peto*, I seek.

of which the planets are retained in their orbits, are called the central forces. I shall now proceed to explain in what manner these central forces affect the motion of a planet in an elliptic orbit.

Let S, fig. 16., be the Sun, and P the place of a planet moving under the impulse of a projectile force, by which it describes the line P A in a given particle of time; in the second particle of time, if nothing opposed its progress, it would describe the line A *b*, but at A let the centripetal force act upon it by a single impulse, sufficient to carry it from A to *a* in the time that the planet would have described the line A *b*; complete the parallelogram *a* A *b* B, at the end of the second particle of time the planet will arrive at B, having described the diagonal A B, by the joint effect of these two forces. Now, because A *b* = P A, the triangle P S A = the triangle A S *b*. But, because *b* B is parallel to A *a* S, the triangle A S B is equal to the triangle A S *b*, as standing upon the same base A S[1]. Therefore the triangle A S B will be equal to the triangle A S P. If at B the planet receive a new impulse, in the direction B S, a new change of direction B C will be effected, and thus, by a succession of new impulses, exerted at equal intervals of time, and all directed towards the same centre, a polygon will be produced round S, and the triangles formed by lines drawn to S from the several points at which the new impulses are exerted, may be easily proved in the manner shown above to be equal to one another. Hence it follows, that a force directed towards S, together with the projectile force first given to the planet, causes it to describe about S, equal areas in equal times. Now, if we suppose the intervals of time at which these

[1] Eucl. lib. 1. prop. 37.

impulses act to be infinitely diminished, the triangles will become infinitely diminished likewise, and the sides of the polygon being thereby infinitely increased in number will ultimately generate a curve.

The species of curve thus produced must be determined by circumstances. I shall, therefore, proceed to consider those circumstances under which the projectile and centripetal forces are compounded together in the motions of the primary planets round the Sun; to understand which it must be observed: first, that if the projectile force of a planet be duly adjusted to the centripetal, that is, if these two forces be so adjusted, that neither can overcome the other, and if, at the beginning of the revolution of the planets, these forces act at right angles to each other, the planet will be carried round in a circle, in which (meeting with no resistance) it will for ever continue to revolve.

Secondly, if the direction of the projectile force be at right angles to the line of direction of the centripetal force, yet, if these forces be not duly adjusted to each other, the planet will not describe a circle but an ellipse; and according as the centripetal force is too strong for the projectile, or the projectile too powerful for the centripetal, at the time of the planet's motion commencing, so will the point from which the planet sets out become the aphelion or the perihelion point of its orbit.

Thirdly, if the projectile and centripetal forces be duly adjusted to each other in the manner above mentioned, yet if the two forces thus adjusted act at oblique angles to each other, that is, if the line of the projectile force make an oblique angle with the line of direction of the centripetal, the planet will revolve in an ellipse, having the Sun in one of the foci.

To exemplify the foregoing observations, let us suppose A, fig. 17, to be the place of a planet at the commencement of its revolution round the Sun, situated at S. If the projectile force acting in the direction of the line A *a b c* be so adjusted to the force of gravity, or the centripetal force acting in the direction A S, that the former of these forces alone would carry the planet from A to *c*, in the same time that the latter would carry it from A to *e*, the planet, by the combined action of these two forces, will describe the arc A *d* in the same time that the projectile force singly would have carried it from A to *c*, or the gravitating power alone would have caused it to descend from A to *e*; and its distance from the Sun, when it arrives at *d*, being the same as it was at A, the curve described by the planet in its revolution round that luminary will be a circle.

In order that a planet may revolve round the Sun in a circle, its projectile velocity must be exactly such as it would have acquired by gravity alone in falling through half the radius of the circle.

But if, while the projectile force alone would carry the planet from A to *a*, the Sun's attraction, or the centripetal force, would carry it from A to *g*, the centripetal force in this case being too great for the projectile, would cause the planet to describe the arc A B, and the distance B S from the Sun being less than the distance A S, this arc will be the portion of an ellipse. While the planet is going through the arc A B, the gravitating power (which always increases as the square of the distance diminishes) becomes stronger, and as it acts in some degree in conjunction with the projectile force, the velocity of the planet's motion will be constantly accelerated, so that when the planet arrives

at M, its mean distance from the Sun, it will have acquired a degree of velocity which would be exactly sufficient to produce a circular motion about S, if its direction were perpendicular to the radius vector, but the line of projection M *m* being oblique to the radius vector M S, the planet is brought still nearer to S. A great portion of the centripetal force being still employed in accelerating the motion as soon as the planet passes M its velocity becomes greater than would produce a circular motion about S. The angle, however, formed by the radius vector and tangent, now increases, whereby this effect of the centripetal force in accelerating the motion of the planet, diminishes, and the path becomes more incurvated. The velocity of the planet is, notwithstanding, still accelerated, the radius vector passing over equal areas in equal times, and this acceleration continues till the planet reaches its perihelion P, when the angle made by the radius vector and tangent becomes a right angle. At P the planet has gained so much centrifugal force, or tendency to fly off, in the tangent P *p*, as overcomes the centripetal force; the path of the planet, therefore, leaving P, falls entirely without the circle whose radius is P S, and consequently the planet is receding from the Sun. There being now a portion of thecentripetal force employed in retarding the motion of the planet, it ascends in the curve V G M', its velocity gradually decreasing, and the angle made by the radius vector and tangent increasing, till the planet arrives at M', where it has the same velocity that it had at M'; the angle S M' *m'* being now as much greater than a right angle as it was less at M. The centripetal force still continuing to act against the projectile motion of the planet, its velocity in consequence thereof decreases, till it again arrives at the point A from

which it set out. The angle formed by the radius vector and tangent decreases from M' to A, where it again becomes a right angle. At A the projectile force being as much diminished from its mean state at M or M' as it was increased at P, the Sun's attraction again becomes more than sufficient to keep the planet from going off at A, and the revolution is repeated in the manner already described.

From the explanation which has now been given of the motion of a planet in an elliptic orbit, it is obvious, that in a non-resisting medium a body may revolve in an ellipse of any degree of eccentricity, and that the less the projectile force impressed upon the body in the higher part of its orbit, the more elliptical will be the path in which it revolves.

LECTURE X.

THE PHENOMENA OF THE SUN, AS SEEN FROM THE EARTH, CONCLUDED. — OF SOLAR AND SIDEREAL TIME. — OF THE EQUATION OF TIME. — THE GENERAL PRINCIPLES OF DIALLING.

It has already been shown, that by the annual motion of the Earth about the Sun, and the declination of its axis from a perpendicular to the plane of its orbit, all the varieties of the seasons are produced, and by the revolution of the Earth about its axis, the vicissitudes of day and night are effected.

Now, the distance of the fixed stars is so immensely great, that in comparison of it, the orbit in which the Earth revolves round the Sun sinks into a mere physical point, in consequence of which, and the uniformity of the Earth's motion on its axis, any given meridian revolves from any fixed star to the same star again in the exact time that the Earth completes a rotation on its axis, and this would likewise be the case with regard to the Sun, provided that the Earth had only a diurnal without an annual motion. But as the Earth while turning once round its axis advances almost a degree eastward in its orbit, if the Sun be on the meridian of any place on a certain day, the Earth must perform something more than a complete rotation, in order to bring the same meridian under the Sun on the day following. The time occupied by the Sun in performing his apparent diurnal

revolution in the heavens, or that in which, by the Earth's motion on its axis, any meridian is carried round from the Sun to the Sun again is 24 hours, and is called a solar day. The time which elapses between two successive transits of any star over the meridian is called a sidereal day, and is 23 hours, 56 minutes, 3·4 seconds in length, being the true period of the Earth's rotation about its axis. The difference, therefore, between a solar and sidereal day is 3 minutes, 56·6 seconds. Hence there are 366 sidereal days in a year, that is, in 365 solar days the Earth performs 366 revolutions about its axis.

To illustrate the foregoing observations, let *a b c d e f g h i k l m n o p q r s t v w x y z*, diagram 5, No. 1., be the orbit in which the Earth revolves round the Sun every year, in the order of the letters, and A any fixed star at such an immense distance, that the diameter of the Earth's orbit bears no sensible proportion to that distance; also, let S, No. 2. of the same diagram, be the Sun, and E the Earth, round which is the horary circle 1 2 3, &c. Having put the parts 1 and 2 of this diagram on the machine, in the usual manner, No. 1 first, and No. 2 upon it, bring the Earth to *a* and turn it, so that the index attached to the meridian E I may point to 12 at noon, or to that 12 which is nearest the Sun. When the Earth is in this situation, the Sun S and the star *a* are evidently both on the meridian of the place I at the same time. If the Earth remained always stationary at *a*, it is obvious that, by its rotation on its axis, the point I would always come round to the Sun and star at the same time, but, by reason of the interposition of the Sun, the star would for ever remain invisible. This, however, not being the case when the Earth, in performing its annual revolution round the Sun, has

advanced, suppose through one twenty-fourth part of its orbit, from *a* to *b*, its rotation upon its axis will bring the point I one twenty-fourth part of a natural day, or one hour sooner to the star than to the Sun, for the whole diameter of the Earth's orbit being but a point compared with the distance A S, the star A will always come to the meridian of the place I when E I is parallel to A S *a*, and therefore the star A which came to the meridian with the Sun at noon, when the Earth was at *a*, will, now it has arrived at *b*, come to the meridian one hour sooner, or at eleven o'clock in the forenoon, as is shown by the index upon the horary circle. When the Earth comes to *c*, the meridian E I will be parallel to A S *a* two hours sooner, and consequently the place I will have the star on its meridian at ten o'clock in the forenoon, as shown by the index, or two hours before it comes round to the Sun. When the Earth arrives at the point *d*, the meridian E I will be parallel to A S *a* at nine in the morning, as shown by the index, the point I will therefore have the star on its meridian three hours before the Sun will arrive at the same meridian. When the Earth comes to *e*, the star will be on the meridian E I at eight in the morning, or four hours before noon; when at *f*, five hours before noon; at *g* the star A comes to the meridian E I at six o'clock in the morning, at which time, as shown by the index, the meridian E I is parallel to A S, and the Earth will have one quarter of a solar revolution, or six hours more to revolve before it is mid-day by the Sun to the place I. When the Earth comes to *h*, the star is on the meridian at five in the morning, or seven hours before noon. When the Earth is at *i*, the star transits the meridian at four in the morning; when at *k*, at three in the morning; at *l*, at two in

the morning; at *m*, at one; and at *n*, the Earth having gone half round its orbit, the Sun and star with regard to the Earth will be in exactly opposite points of the heavens, and the star will come upon the meridian of the place I at midnight, or twelve hours before the Sun; and thus, by bringing the Earth successively to the situations *o p q r s t v w x y z* back to the point *a*, at which its annual revolution commenced, and noticing the hours pointed out by the index on the horary circle, it will be found, that for every one of these divisions passed over by the Earth in its revolution round the Sun, the star has gained one hour upon the Sun, so that when the Earth arrives at *a*, the Sun and star will again come upon the meridian together, but the rotations made by the Earth on its axis during the time of its performing a complete revolution in its orbit, will be one more in number than the noons experienced by the inhabitants at I, or the number of times they have had the Sun on their meridian, for a rotation of the Earth is completed when E I or any particular meridian comes to be parallel to the situation it had at the time that rotation commenced. Now it is plain, that by reason of the Earth's motion in its orbit, it never brings the same meridian round from the Sun to the Sun again by turning once round its axis, for the Earth obviously requires as much more in proportion, of another rotation on its axis, to complete a natural day, as it has advanced in its orbit during that time, namely, about one 365th part at a mean rate, and consequently in 365 days the Earth must perform 366 rotations, and since each rotation completes a sidereal day, there must be 366 sidereal days in a year; or, to speak in a more general manner, since a rotation of any planet about its axis is the length of a side-

real day to that planet, the number of sidereal days will always exceed the number of solar days by one, let that number be what it may, one rotation being always lost in the course of an annual revolution by the planet's going round the Sun.

The Earth's motion about its axis being perfectly equable and uniform in every part of its annual revolution, the sidereal days are always of the same length, but the solar or natural days vary very considerably at different times of the year. This variation is owing to two distinct causes: viz. the inclination of the Earth's axis to its orbit, and the inequality of its motion round the Sun. From these two causes, therefore, it is, that the time shown by a well-regulated clock and a true Sun-dial is scarcely ever the same. The difference between them is called the equation of time, or the equation of natural days.

If the ecliptic, or the circle in which the Sun appears to move round the Earth, were coincident with the celestial equator, that is, if the Earth's axis were perpendicular to the plane of its orbit, equal portions both of the equinoctial and the ecliptic would pass over the meridian in equal times; but on account of the ecliptic being inclined to the equinoctial, unequal portions of the former pass over the meridian in equal times, the difference being always proportional to the obliquity, and as the obliquity is much greater in some parts of the ecliptic than in others, these differences will be unequal among themselves.

In explaining this part of the equation of time, there is, perhaps, no better method than that usually adopted of supposing two Suns to move round the heavens, the real Sun describing equal portions of the ecliptic, and a fictitious one equal

portions of the equinoctial in equal times, and imagining these Suns both to set out at the same time from the same point; namely, the beginning of Aries, where the real Sun is on the 21st of March. Now, the plane of the equinoctial being perpendicular to the axis of rotation of the sphere, the equatorial Sun would always return to the meridian in 24 hours time, as shown by a well-regulated clock, but the real Sun would return to the meridian sometimes sooner and sometimes later than the fictitious or equatorial Sun, and these two Suns would arrive at the meridian precisely together only four times during the whole period of their annual revolution. While the two Suns are describing the first quarter of their circuit round the heavens, viz. from Aries to Cancer, the equinoctial Sun will precede the Sun in the ecliptic, and as the apparent diurnal motion of the celestial sphere is in a contrary direction to that of the Sun's apparent annual motion, the Sun in the ecliptic will, by the diurnal motion above mentioned, come sooner to the meridian than the Sun in the equinoctial, and consequently the Sun-dial will be faster than the clock. At the beginning of Cancer, or on the 21st of June, both Suns will come to the meridian at the same instant, and the dial and clock will exactly coincide; but in their progress through the second quadrant, or in going from Cancer to Libra, the Sun in the ecliptic will get before the equinoctial Sun, and will therefore come later to the meridian, and consequently the clock will be faster than the Sun-dial; at the beginning of Libra, however, both Suns again come to the meridian at the same time, and therefore the dial and clock again coincide: this takes place on the 23d of September. As the two Suns advance through the third quadrant, from Libra to the

beginning of Capricornus, or from the 23d of September to the 21st of December, the Sun in the equinoctial again takes the lead, and the dial will be faster than the clock. While the two Suns are describing the last quarter, or moving from Capricornus to Aries, the Sun in the equinoctial falls behind the real Sun, or the Sun in the ecliptic, and consequently the dial will be slower than the clock; on the 21st of March, the two Suns once more come to the meridian together, and the dial and clock again coincide.

The foregoing explanation of that part of the equation of time which results from the obliquity of the ecliptic, may be very familiarly and beautifully illustrated, by placing patches at every tenth or fifteenth degree of the equator and ecliptic of a common terrestrial globe, beginning both from the first point of Aries. Then, by revolving the globe on its axis, all the patches from Aries to Cancer on the ecliptic will arrive at the meridian before those on the equator, showing that the Sun during that time is before the clock; when Cancer comes to the meridian, the patches on the ecliptic and equator arrive at the meridian together, the sun-dial and clock, therefore, on that day coincide. From Cancer to Libra the patches on the equator arrive at the meridian before the corresponding ones on the ecliptic, from which it is evident, that during the time of the Sun's describing this portion of his apparent annual revolution, the clock is before the Sun, or that the Sun during that interval does not come upon our meridian till after the time of noon, as shown by a well-regulated clock. By the intersection of the ecliptic and equator, which takes place at the beginning of Libra, the Sun and clock are again found to coincide when that point comes to the meridian. From the be-

ginning of Libra to the beginning of Capricornus, the patches on the ecliptic come to the meridian before those on the equator, and consequently the Sun is before the clock. At the beginning of Capricornus they again coincide, and from the beginning of Capricornus to the beginning of Aries, where the revolution commenced, the clock is again before the Sun, as is shown by the patches on the equator coming to the meridian before those on the ecliptic.

From what has now been said, it appears, that the time shown by the clock corresponds with that shown by the dial only four times in the year; namely, at the time of the equinoxes and solstices; throughout all the rest of the year the one is alternately faster and slower than the other; thus, from March to June the dial is faster than the clock, from June to September slower, from September to December the dial is again faster, and from December to March slower.

Having explained in what manner the obliquity of the ecliptic operates as one cause of the difference of time shown by a correctly-going clock and a true Sun-dial, I shall now proceed to consider the other cause of this difference, namely, the inequality of the Earth's motion in its orbit, or of the Sun's apparent annual motion in the ecliptic.

We have already observed, that by the annual motion of the Earth round the Sun, that luminary, as seen by a spectator on the surface of our globe, appears to go round in the ecliptic in the order of the signs. It has also been shown that the orbit in which the Earth revolves is elliptical, and that its motion therein is not equable, consequently the apparent motion of the Sun in the ecliptic will evince the same inequalities, and accordingly we find that he sometimes describes more than 59 minutes,

8·3 seconds, in a day, which is his motion at a mean rate, and sometimes less, thus producing that other part of the equation of time already alluded to, and which I shall now endeavour to explain by once more transferring the motion of the Earth to the Sun, again calling in the aid of a fictitious Sun, and supposing it, as well as the real Sun, to move in the ecliptic, but the former with an equable motion, describing equal arcs in equal times, while the latter Sun, revolving with a motion alternately accelerated and retarded, in equal times passes through unequal arcs.

Let us now suppose these two Suns to start at the same instant from the apogee, or that point of the ecliptic in which the Sun is most distant from the Earth. The motion of the real Sun being now the slowest, the fictitious Sun, whose motion is always uniform, will immediately get before him, and will gain upon him so much, that the real Sun, notwithstanding his motion is constantly increasing while moving from the apogee to the perigee, will not overtake the fictitious Sun till he arrives at the latter point, which they will both reach at the same instant of time, and as the velocity of the real Sun is then a maximum, he will pass the fictitious Sun, and will so far gain upon him in this part of his career, that although the motion of the real Sun is now as constantly retarded as it was accelerated while approaching the Earth, yet the fictitious Sun will not overtake him till they again both reach the apogee whence they set out. Hence, it is evident, that in moving from apogee to perigee, or while the Sun is approaching the Earth, the real Sun will as it were be left behind by the fictitious Sun, while, on the other hand, in moving from the perigee to the apogee the real Sun gets ahead of

the fictitious one. Since, therefore, the diurnal motion of the sphere (as was before observed) is in an opposite direction to the Sun's annual motion in the ecliptic, that Sun which is behind must obviously come to the meridian sooner than the other, and therefore, from July to January the dial will be faster than the clock, and from January to July the clock will be before the dial.

It appears, therefore, that the obliquity of the ecliptic to the equator, which was the cause first taken into consideration, would make the dial and the clock agree on four days of the year, namely, those on which the Sun enters Aries, Cancer, Libra, and Capricornus, but the unequal motion of the Earth in its orbit would only produce a coincidence between them twice in the course of that time, that is, when the Sun is in apogee and perigee. When, therefore, the Sun is in these points at his entrance into Aries and Libra, or into Cancer and Capricornus, the two causes will unite in making the dial and clock agree in those points. The Sun's apogee at present is in about the tenth degree of Cancer, and his perigee in the tenth degree of Capricornus; consequently the dial and clock cannot coincide at the entrance of the Sun into these signs, nor, in fact, at any time of the year except where the equation arising from one cause becomes a counterpoise to that which results from the other.

By the explanation which has now been given of the two causes of the equation of time, or difference between the time shewn by a well-regulated clock and a true Sun-dial, it will be seen that the dial is sometimes slower from the one cause and faster from the other, sometimes faster or slower from both causes, and sometimes the effect of the one is counterbalanced by that of the other.

It is to be observed, therefore, that when one of the equations is faster, and the other slower, the true equation is found by subtracting the less from the greater, and when they are both faster or both slower, by adding them together.

The equation of time, as now described, is subject to some variations, which, although proper to be mentioned, are so trifling, that for all common purposes they may be very safely neglected in calculation.

The first arises from the derangement of the Earth's motion by the Moon, Venus, Mars, and Jupiter, whereby the equation of time must of course be effected. This variation, however, amounts at a maximum to only 2·2 seconds. The increase or decrease of the obliquity of the ecliptic is also attended with a proportional increase or decrease in the equation of time; this amounts at a maximum to no more than 1·5″ in the course of two centuries.

The second part of the equation of time, which is nothing more than the difference between the mean and true place of the Sun, converted into time, commonly called the equation of the Sun's orbit, is subject to a diminution of 1·25 seconds, in a century, arising from a diminution of the equation of the solar orbit at the rate of 18·8 seconds in that time. There is also another variation in the equation of time, arising from the motion of the Sun's apogee; this amounts at a maximum to 14·3 seconds in a century, when the Sun is in the apogeal or perigeal point of his orbit.

Tables of the equation of time will be found in the Nautical Almanack, White's Ephemeris, and in most treatises on Astronomy. The time shown by the sun-dial is called apparent time, and that

which is shewn by a well-regulated clock is called mean time.

The Sun-dial being employed in determining some of the most important solar phenomena, no apology, it is presumed, need be offered, for introducing in this place a description of that useful instrument, with an account of the principles upon which it is constructed.

A Sun-dial is a plane whereon certain lines are described, in such a manner that the shadow of a wire, or of the upper edge of a plate-stile, perpendicular to the plane of the dial, may point out the exact time of a solar day. The edge of the plate, by the shadow of which the time of the day is found, is called the stile of the dial, and the line on which the said plate is erected is called the substile. The angle included between the stile and substile is the elevation or height of the stile.

Sun-dials are of various kinds according to the position of the planes upon which they are delineated. Those whose planes are parallel to the plane of the horizon are called horizontal dials, and those dials whose planes are perpendicular to the plane of the horizon, are called erect or vertical dials; vertical dials, whose planes exactly front the north or south, are denominated direct north or south dials: vertical dials, whose planes do not face the north or south, are called decliners, because their planes decline from those points. Those dials whose planes are neither parallel nor perpendicular to the plane of their horizon, are named inclining or reclining dials, according as their planes make acute or obtuse angles with the plane of that circle, and if, moreover, the planes of these inclining or reclining dials are turned aside from facing the north or south, they are called declining-inclining or declining-reclining dials. There are

various other sorts of dials, not necessary to be here spoken of, and for an account of which reference must be made to authors who professedly treat upon the subject of dialling.

The face of every Sun-dial represents the plane of some great circle upon the Earth, and the gnomon or stile the Earth's axis, whether it be a small wire or the edge of a thin plate, as in most common horizontal dials. In order to explain this, let N B S D, fig. 18. be the Earth, supposed in this instance to be hollow and transparent like a sphere of glass, let us also imagine its equator to be divided into twenty-four equal parts, by so many meridian semicircles, *a b c d e f g*, &c., one of which (*a*) is the geographical meridian of London (supposed to be at L); if the hours of XII. be marked upon that meridian and the opposite one, and all the rest of the hours in order on the rest of the meridians, those meridians will be the hour-circles of London; then if the sphere have an opaque axis N E S, upon which it revolves, whenever by the motion of the Earth the Sun comes to the plane of any particular meridian, the shadow of the axis will fall upon the opposite meridian, and will consequently show the time at London, and at all places upon the same meridian. If now we imagine a solid plane A B C D to pass through this sphere in the rational horizon of London, the half N E of the axis will be above the plane, and the other half below it, and, therefore, the shadow of half the axis will always fall upon one side or the other of this intersecting plane, that is, the shadow of the upper half N E of the axis, will fall somewhere upon the upper side of the plane A B C D, while the Sun remains above the horizon, and the shadow of the lower half E S will fall upon the lower side of the same plane when the Sun is

below the horizon of London. If, therefore, straight lines be drawn from the centre E of the plane to those points where its circumference is cut by the hour-circles of the sphere, those lines will be the hour-lines of a horizontal dial for London, for the shadow of the axis will fall upon each particular hour-line of the dial when it would have fallen upon the corresponding hour-semicircle of the sphere.

The hour-lines being thus found by the intersecting points of the hour-semicircles, it is evident, that if these semicircles be supposed removed, and the horizontal plane with the half of the axis above it be alone left, this plane will be a correct horizontal Sun-dial, the gnomon or stile of which is formed by the half axis remaining in the position already described. Hence the reason why the gnomon of those dials in our latitude is always directed to the north pole, and always forms with the XIIth hour-line C B, such an angle N E B as is equal to the latitude of the place. It is also to be observed, that on these dials only sixteen hour-lines are drawn, being as many as are required for those hours during which the Sun is above the horizon on the longest day. These lines are all drawn from VI. to XII. and VI. again on the northern, and the rest on the southern part of these dials; the hour-line of VI. lying directly east and west, as that of XII. does north and south. Those hour-lines which serve for the forenoon lie on the west side of the plane, and are numbered from west to north, and those which serve for the afternoon hours lie on the east side, and are numbered from north to east.

In the foregoing illustration the plane of the horizon has been taken for the intersecting plane, and consequently a horizontal dial was produced;

if, however, any other plane be chosen for an intersecting plane, and lines be drawn from the centre of this plane to the points in the circumference through which the hour-circles pass, we shall obtain the hour-lines for that plane: thus, if the plane which cuts the sphere be perpendicular to the horizon, as A L B D, fig. 19, touching the given place London at L, and directly fronting the meridian of London, it will then become the plane of a vertical direct south dial; if, therefore, right lines be drawn from its centre E to those points of its circumference which are cut by the hour-circles of the sphere, these right lines will become the hour-lines of a vertical or direct south dial for London, on which the hours are to be placed in a contrary direction to those on a horizontal dial, as is shown in the figure, the lower half, E S of the axis N E S, casting a shadow on the hour of the day in this dial at the same time that it would fall upon the corresponding hour-semicircles of the sphere, were the plane of the dial removed out of the way. If the intersecting plane (still facing the south) be made to incline or recline by any given number of degrees, the hour-semicircles of the sphere will still cut the edge of the plane in those points to which the hour-lines must be drawn straight from the centre, and the axis of the sphere, which is still the stile or gnomon of the dial, will cast a shadow on these lines at the respective hours. The same takes place if the plane be made to decline from the meridian any given number of degrees less than 90, or provided the reclination be less than the co-latitude[1] of the place, the axis of the sphere being still a gnomon or stile for the dial.

[1] The co-latitude or complement of the latitude is what the latitude of a place wants of 90 degrees.

But when the declination is 90°, or the reclination is equal to the co-latitude, the axis ceases to be a gnomon, because in both these cases the axis has no elevation above the plane of the dial.

The bulk of the Earth when compared with its distance from the Sun, being but a point, if a small sphere of glass having such lines upon and such a plane within it, as above described, with facilities for setting the inclosed plane to any given position, be placed upon any part of the Earth's surface, so that its axis be parallel to the axis of the Earth, (the plane being duly adjusted,) the particulars I have been describing will be thereby exhibited, and the hours of the day shown as truly as in the globe of the Earth, supposed transparent, or as they would be in this small sphere placed at the Earth's centre.

To give a correct idea of the principles of dialling, a brass sphere is sometimes employed, consisting of twenty-four semicircles sliding over each other upon a moveable horizon.

From what has now been said, it is obvious that the universal principle on which this art depends, consists in finding where the shadow of a wire, or of the edge of a thin plate, parallel to the Earth's axis, (which the gnomon, of whatever kind it may be, always represents), will fall on a given plane every hour,* half-hour, &c. Now, it has already been shown, that the position of the hour-lines is determined by means of the hour-semicircles, the art of dialling, therefore, is for the most part reduced to finding the intersecting points of the hour-semicircles for all kinds of planes. These may be determined in various ways, and although the method of constructing Sun-dials cannot certainly be said, properly speaking, to belong to the science of Astronomy, yet, as many persons studying that

science may be desirous of becoming acquainted with some easy method of making a common horizontal dial, I trust I shall incur no severe censure by concluding this subject with directions for that purpose; and as the methods I am now about to describe, being purely mechanical, and consequently requiring no mathematical knowledge, nor any acquaintance with logarithmic calculation, may be put in practice by any person who feels disposed so to do, I flatter myself they will prove the more acceptable on that account.

Elevate the pole of a common terrestrial globe, having the twenty-four meridian-semicircles drawn upon it, equal to the latitude of the given place, and turn it upon its axis till any one of the meridians cuts the horizon in the north point, where, suppose the hour of XII to be marked, the rest of the meridians will cut the horizon at the respective distances of all the other hours from XII. Let these points, therefore, be accurately marked upon the horizon, after which, taking the globe out of the stand, fit in a piece of board or a plate of any kind even with the surface of the horizon. Then if straight lines be drawn from the centre of the board to those points of distance on the horizon which were intersected by the meridian-semicircles, these lines will become the hour-lines of a horizontal dial for that latitude, the edge of whose gnomon must of course occupy the exact place of the axis of the globe previous to its being taken out of the frame, that is, the gnomon must make an angle with the twelve-o'clock-line equal to the latitude of the place for which the dial is made.

As it is possible that every person who would wish to make a dial may not be provided with a globe, I shall now show how to perform it by means of the plain dialling-lines, or scale of latitudes

and hours, *fig.* 20. These scales, the expence of which is very trifling, are to be had of all mathematical instrument makers.

Having drawn a double meridian-line, *a b c d*, fig. 21, on the plane intended for a horizontal dial, and crossed it at right angles by the six-o'clock-line *e f*, take the latitude of the given place in your compasses from the line of latitudes on the dialling scale, and set off that extent from *c* to *e*, and from *a* to *f* on the six-o'clock-line; next, from the line of hours on the same scale take the whole six hours in the compasses, and setting one foot in the point *e*, let the other foot fall where it will upon the meridian line *c d*, as at *d*; do the same from *f* to *b*, and draw the right lines *e d* and *f b*, each of which will of course be equal to the whole scale of hours. This done, set one foot of the compasses at XII, in the beginning of the line of hours on the dialling scale, and extending the other to each hour on that line, lay off these distances from *d* to *e* for the afternoon hours, and from *b* to *f* for those of the forenoon, the lines *d e* and *b f* will thus be divided in the points 1 2 3 4 5 6, in the same manner as the hour-line on the scale is divided at I. II. III. IV. V. VI. In the same manner the half hours and quarters may be laid down if required. Every thing being thus prepared for drawing the hour-lines, lay a ruler on the point *c*, and draw the first five afternoon hour-lines from that point through the points 1 2 3 4 5 on the line *d e*, continuing the IVth and Vth hour-lines through the point *c* to the other side of the dial, for the like hours of the morning. This done, lay the ruler on the point *a*, and draw the last five hour-lines in the forenoon through the points 5 4 3 2 1 on the line *f b*, continuing the hour-lines of VII. and VIII. through the point *a* to the other side of

the dial for the like afternoon hours, and set the hours to their respective lines as in the figure.

Lastly, at the point *a* (either by a protractor or a line of chords) make the angle *g a h* equal to the latitude of the place for which the dial is constructed, and draw the line *a g*, from *g* let fall the perpendicular *g h* upon the meridian line *a b*, and there will be a triangle formed whose sides are *a g*, *g h*, and *h a*. If a plate be made similar to this triangle, and as thick as the distance between the two lines *a b* and *c d*, and set upright between them, touching at *a* and *c*, its hypothenuse *a g* will be the gnomon of the dial, and when the dial is truly set, being parallel to the axis of the world, will cast a shadow on the hour of the day. The hour-lines being less distant from each other about noon than in any other part of the dial, it is best, in order to enlarge the hour-distances thereabout, to have the points from which the hour-lines are drawn a little distance from the centre of the dial-plane on the side opposite to XII. Thus C is the centre of the plane, but the points *a* and *e*, at some distance from it, are the points from which the hour-lines are drawn.

As it is by no means my intention to go deeply into the art of dialling, I shall now, having shown two very easy methods of constructing that kind of dial most generally used, proceed to point out in what manner a dial when made may be set due north and south, as without some method of doing this, the dial, though ever so truly constructed, will become entirely useless. Now, in order to do this, it is necessary to have a true meridian line, or a line which, if produced, would pass through the poles of the Earth and the spot where the dial is to be placed.

On a smooth horizontal plane describe three or

four concentric circles, as 1 2 3, fig. 22, and in the common centre C, fix perpendicularly a wire B C, having a round blunt point, and of such a length that the extremity of its shadow may fall within the outermost circle, at least three hours before noon. Observe in the forenoon when and in what points the extremity of the shadow just touches the several circles, and make marks at those points.

In the afternoon of the same day make similar observations, marking the points of contact on the circles as before. Then taking any circle in which two dots are found, as suppose A D in circle 2, and with any convenient opening of the compasses and the centre A, describe the arch *a b*, then with the same radius and the centre D, describe the arc *c d*, intersecting *a b* in the point *e*: lastly, through the points C and *e*, draw the line C *e*, which will be the meridian-line required. The advantage to be derived from drawing several circles is, that in case of missing the time when the point of the shadow is just in contact with one circle, you may catch it when it touches another. If the weather prove so favourable that both points can be marked on more of the circles than one, let the same operation be performed with as many of the circles as both points can be obtained upon, and take a mean of all the bisecting lines for a meridian.

This method of drawing a meridian-line evidently supposes that the Sun's declination does not change during the interval between the observations; as, however, the Sun's declination undergoes a perceptible change in the space of four or six hours at certain times of the year, about the equinoxes for instance, it will be proper, in order to avoid as much as possible

any inaccuracy from this cause, to make the observations about the time of the Summer solstice, at which season of the year the Sun changes his declination so slowly as to create no error worth regarding.

LECTURE XI.

THE PHENOMENA OF THE PRIMARY PLANETS AS SEEN FROM THE EARTH. — THE APPARENT MOTIONS OF THE INFERIOR PLANETS MERCURY AND VENUS. — OF TRANSITS. — ON PARALLAX. — THE METHOD OF FINDING THE SUN'S HORIZONTAL PARALLAX FROM THE TRANSITS OF VENUS. — THE PARALLAX OF THE SUN BEING KNOWN, HIS DISTANCE FROM THE EARTH EASILY ASCERTAINED, AND THENCE BY ANALOGY, THE DISTANCES OF ALL THE PLANETS FROM THE SUN.

HAVING concluded our observations upon the solar phenomena, (for eclipses of the Sun, hereafter to be treated of, being caused by the interposition of the Moon, cannot be properly comprehended under that head,) the apparent motions, &c. of the primary planets will next claim our attention.

The true motion of these bodies in their respective orbits, which is according to the order of the signs, is called direct or *in Consequentia*; but their apparent motion is sometimes contrary to the order of the signs, and is then said to be retrograde or *in Antecedentia*. Since the planets all revolve round the Sun with different velocities, their situations relatively to each other must, of course, be perpetually changing, by which change of position certain configurations take place among these bodies, arising from their different longitudes measured on the ecliptic; these are denominated

their aspects [1] of which the ancients reckoned five, namely, Sextile, Quartile, Trine, Opposition, and Conjunction. The Sextile aspect which is thus marked ✱ is, when the planets are the sixth part of a circle, or 60° from each other. The Quartile or quadrate aspect, marked □, when they are 90°, or a quarter of a circle apart. Trine, marked △, when one third of a circle, or 120° distant. Opposition, marked ☍, when half a circle or 180° from each other. And Conjunction, marked ☌, when two or more planets are in the same degree of the ecliptic.

These terms are also applied in the same manner to any two of the heavenly bodies; thus, the Sun and Moon, the Sun, or Moon, and any planet, &c. may, in like manner, be in Conjunction, Opposition, Trine, Sextile, &c. The introduction of these aspects is doubtless to be attributed to astrologers, by whom they were distinguished into benign, malign, and indifferent; the Quartile and Opposition were considered malignant; the Trine and Sextile, benign or friendly; and the Conjunction, indifferent. Kepler, who added eight new ones to those previously known, defines an aspect to be the angle formed by the rays of two planets meeting upon the Earth, whereby their good or bad influence is determined.

It has already been remarked, that the planets Mercury and Venus, revolving round the Sun in orbits which are comprehended by the orbit of the Earth, are called inferior planets, and that Mars, Jupiter, Saturn, and Uranus, whose orbits include that of the Earth, are called superior planets, the connecting link between which and the inferior is the Earth that we ourselves inhabit. Now, in pursuing our investigations relative to these bodies,

[1] From *aspecto* to look stedfastly.

we shall find that each presents phenomena peculiar to the class to which it belongs; it will be proper, therefore, to treat of them according to this arrangement, beginning with the inferior planets Mercury and Venus.

These planets are never seen at any great distance from the Sun, and Mercury being the nearest to that luminary, and the least in magnitude, is very seldom visible; it is only, therefore, just after the setting of the Sun in the evening, or a little before his rising in the morning, that we can be indulged with a sight of this planet. When Mercury first makes its appearance after Sun-set in the west, he resembles a brilliant twinkling star; but by continuing our observations during a few succeeding evenings, he will be easily distinguished from the fixed stars by a small progressive motion, whereby his distance from the Sun increases till it becomes (at a mean rate) about 22 or 23°, when, having attained his greatest elongation or distance from the Sun, he appears for some time stationary, after which he moves backwards in a retrograde direction towards the Sun; the time that elapses between the setting of that luminary and the planet (which never exceeds an hour and fifty minutes) daily decreases, until at length, the latter plunges into the Sun's rays, and is altogether lost to our sight; after which, if we observe the heavens just before Sun-rise in the morning, we shall soon discover the same planet, whose distance from the Sun again increases, till it is about 22 or 23°, when, after being a second time stationary, he again returns towards the Sun. The greatest elongation of Mercury, or its greatest apparent distance from the Sun, is not always the same, but varies from about 17° 30′ to 28° 20′.

The apparent motions of Venus are exactly similar to those of Mercury, but being exterior to

that planet, she recedes farther from the Sun, as seen from the Earth, her greatest elongation varying from 44° 57′ to 47° 48′, and from the slowness of her motion, her stations and retrogradations are less frequent than those of Mercury.

The cause of these phenomena will be understood from diagram 6, which consists of three pieces, numbered 1, 2, and 3. Let T, No. 1, of this diagram represent the Earth, *a b c d e f g h* the orbit of Mercury, and A B C D E F G H the orbit of Venus, also let *m*, No. 2, be Mercury, and V, No. 3, Venus, and in both let S be the Sun. For the purpose of showing the angular distances of Mercury and Venus from the Sun in different parts of their orbits, a graduated circle is attached to the Earth, from the centre [1], of which also proceeds a silk thread or string, representing the visual ray, or the line in which the planet is seen by an observer at T. Part 1 of this diagram being put on the machine in the usual manner, let the Earth be brought to coincide with the first point of Capricornus, then placing part 2 on the machine in the same manner, and bringing Mercury to *a*, the diagram is prepared for illustrating the apparent motions of that planet.

Now, as the eye alone will not enable us to form a true estimate of the distances of objects whose

[1] It may appear at first sight that the visual ray should proceed from that part of the Earth which is turned directly towards the Sun, rather than from the Earth's centre; as, however, the orbits of Mercury, Venus, and the Earth, are laid down in the diagram upon a scale according to their respective mean distances from the Sun in round numbers, it is essential to the illustration, that the visual line should proceed from that point of the orbit in which the Earth is supposed to be placed; it is moreover obvious, that were the figure representing the Earth made in true proportion to its distance from the Sun in the diagram, its diameter would be infinitely less than the thickness of the string itself.

remoteness is so considerable as that of the heavenly bodies, the Sun and Mercury (if it could be seen) would both appear to an observer at T to be *in the opposite point of the ecliptic, or in the first* point of Cancer; Mercury, however, being between the Earth and Sun, will be invisible because his enlightened side is turned from the Earth, unless he be at the time in one of his nodes, in which case he will appear like a dark spot on the Sun's disc. The silk string which represents the visual line being passed over the centre of Mercury and the Sun, and extended to the ecliptic, will cut the first point of Cancer, and render the foregoing observations clearly understood. In like manner, this string being kept constantly stretched over the centre of the planet, and extended to the ecliptic, while the planet is made to revolve round the Sun, will show the vibratory motion of Mercury with regard to the Sun in that circle; but its angular distance from that luminary in each particular point of its orbit, must be sought for on the graduated semicircle attached to the Earth, for the Earth's orbit being but a point compared with its distance from the fixed stars, it is obvious, that the ecliptic must be referred to an indefinite distance from the Sun and Earth, and consequently, in any figure we can construct for the purpose of illustrating this subject: the angular distance between the Sun and planet must always be shown by some such method as that above mentioned, the references, therefore, made to the ecliptic on the machine in the present instance, are merely intended to show that the interior planets are in a state of continual oscillation about the Sun, their angular distances from which, as before observed, must be determined by the semicircular arc attached to the Earth for that purpose.

When Mercury arrives at *b* in its orbit, it appears in about 5° of Gemini in the ecliptic, as seen from the Earth, its angular distance from the Sun being about 12°.[1] When Mercury is at *c* in his orbit, he appears at his greatest western elongation or distance from the Sun, which, as shown by the graduated arc, is about 22 or 23°; in this situation he appears to remain for some time stationary, neither receding farther from the Sun, nor advancing nearer to him, but as Mercury moves from *c* to *d*, he appears to return towards the Sun, and seems to be in the same point of the ecliptic, and at the same angular distance from the Sun when at *d* as when he was at *b*, but of a much smaller size. At *e* he is lost to the observer at T, behind the Sun. While Mercury is moving from *e* to *f*, he appears to recede from the Sun eastwards, and at *f*, his apparent magnitude and his angular distance from that luminary are the same as they were at *d*, his apparent place in the ecliptic being about 25° of the sign Cancer. When Mercury gets to *g* in his orbit, he is at his greatest eastern elongation, where he again becomes stationary. In going from *g* to *h* in his orbit, he seems to go back again in the heavens towards the Sun, his distance from which at *h* is the same as it was at *f*, but on account of his proximity to the Earth, his apparent magnitude

[1] This example at once sets the foregoing observations in a clear point of view. Thus, were the distance of Mercury from the Sun to be measured on the ecliptic, it would be found to be almost 30°, whereas, by the graduated arc, it is shown to be no more than about 12°, but were the ecliptic so considerably enlarged, that the distanee between the Sun and Earth, in comparison of it, became a mere point, the Earth might then be considered as the centre of that circle, and consequently, the angular distance between the Sun and Mercury, measured on the ecliptic so extended, would coincide with that shown by the arc above mentioned.

is much increased, being the same as it was at *b*. When Mercury comes to *a* in his orbit, he again passes by the Sun, and disappears as before.

While Mercury is going from *c* to *g* in his orbit, or from his western to his eastern elongation, his motion will appear direct, or according to the order of the signs that is in the direction of his real motion, but from *g* to *c*, that is, from his eastern to his western elongation, his apparent motion will be retrograde, or contrary to the order of the signs; and as Mercury describes a much greater portion of his orbit in moving from *c* to *g* than from *g* to *c*, he appears longer direct than retrograde. When Mercury is at *a* in its orbit, so as to be between the Sun and Earth, he is said to be in inferior conjunction with the Sun, and when Mercury is at *e*, he is behind the Sun with regard to the Earth, and is said to be in superior conjunction with that luminary. In the former of these situations he is also said to be in his perigee or nearest the Earth, and in the latter, in his apogee or farthest from the Earth. The angle at the Sun, formed by two lines drawn to him from the Earth and Mercury, or any other planet, is called the anomaly of commutation of that planet. The apparent longitude of Mercury or any other planet as seen from the Earth, is called its geocentric longitude, and the longitude it would have if viewed from the Sun's centre is called its heliocentric longitude.

Now, removing part 2, and putting part 3 of the same diagram (consisting of the Sun and Venus) in its place, let Venus be brought to A; in this situation, like Mercury at *a*, she is in her inferior conjunction and disappears because her dark side is turned towards the Earth, unless, as was observed of Mercury when in a similar point of

its orbit, she be at the time in one of her nodes, in which case she will appear like a dark spot upon the Sun. In moving through the arc A B of her orbit, she appears to recede from the Sun westward, and when at B, having arrived at her greatest western elongation, she will appear for some time stationary, her angular distance from the Sun as shown by the graduated arc already described, being, at a mean rate, about 46°. While moving from B to E through the arc B C D E of her orbit, she will seem to advance towards the Sun, and at E will disappear, being in her superior conjunction with that luminary, like Mercury at *c*. In going from E to H, she appears to recede from the Sun eastward, and at H is at her greatest eastern elongation, where she once more appears stationary, after which, while moving from H to A, she seems to return towards the Sun, and at A, having her dark side once more turned towards the Earth, she is again lost to our view.

The apparent motion of Venus while going from B to H in her orbit, or from her western to her eastern elongation, like that of Mercury in going from *c* to *g*, is direct, or according to the order of the signs, and while going from *g* to *c*, or from her eastern to her western elongation, it is retrograde or contrary to that order, like the apparent motion of Mercury from *g* to *c*; but like that planet, she appears much longer direct than retrograde, because she describes a much larger portion of her orbit in the former instance than in the latter. While Venus is going from her superior conjunction at E, to her inferior conjunction at A, she is seen on the east side of the Sun, as viewed from the Earth, and, therefore, remains above the horizon in the evening after the Sun has set, for the Sun being then westward of Venus, must obviously

arrive at, and sink below the western verge of the horizon before Venus, who is therefore then denominated the Evening Star. From her inferior conjunction to her superior, she appears on the west side of the Sun, and consequently rises before him in the morning; for which reason she is then called the Morning Star. In describing the telescopic appearances of the planets, it has already been observed, that Mercury and Venus exhibit to us nearly all the different phases of the Moon; thus, after the inferior conjunction of these planets, that is, when they are first seen rising before the Sun in the morning, they appear like the Moon about four days old, shining with a fine luminous crescent. This luminous crescent increases in breadth with the increase in the apparent distance of these planets from the Sun, and when they have attained their greatest western elongation, they appear like the Moon at the first quarter. As they are seen to return towards the Sun, their disc becomes gradually more illuminated, and at the time of their superior conjunction, their enlightened side being turned towards the Sun and Earth, they would appear like the full Moon were they not rendered invisible by the superior brilliancy of that luminary or hid by the intervention of his body, as is the case when they are in either of their nodes at the time of their superior conjunction. When they first become visible in the evening, they appear gibbous, having more than half their disc illuminated. As they approach to their eastern elongation, the enlightened part of their disc diminishes, and when they have reached their greatest eastern elongation, it is again dichotomised or half enlightened. As they appear to return towards the Sun, their luminous disc gradually becomes less and less, till having once more arrived at their inferior

conjunction, their enlightened side is again completely turned away from the Earth. The various appearances of Venus as she revolves round the Sun are exhibited in fig. 23. Venus does not shine with the greatest lustre when she presents the greatest portion of her illuminated disc to our view, for her splendour is at that time diminished by her greater distance from the Earth in a more considerable degree than the illuminated part of her disc presented to us is increased. Venus is brightest when her elongation or apparent distance from the Sun is 39° 44′, in which situation she has been frequently seen in the day time and in bright sunshine.

For the more easy comprehension of the geocentric motions of the inferior planets, the Earth has been hitherto considered as stationary in one particular point of her orbit, while they were revolving round the Sun in theirs, and were this the case, the places of conjunction, both inferior and superior, as also those of greatest elongation, together with the stations of the inferior planets, and their arcs of direct and retrograde motion would be always the same, but by the motion of the Earth in its orbit, all these phenomena are continually advancing forward in the ecliptic; and it is on this account also that an inferior planet is not stationary at the time of its greatest elongation, but some time after, when the planet is approaching the inferior, and before the time it is approaching the superior conjunction.

The greatest elongations of the inferior planets are not always the same, but are subject to continual variations within certain limits: this variation is owing to the elliptical figure of their orbits, and that of the Earth, which produces a variation also in the stationary points and conjunctions of the inferior planets.

If the orbits in which the planets Mercury and Venus revolved round the Sun were in the plane of the ecliptic, these planets would always be seen to traverse the Sun's disc and to pass across its centre in the interval between their disappearing in the evening and their re-appearing in the morning, that is, at every inferior conjunction of these planets with the Sun. It has, however, been shown that the orbits both of Mercury and Venus are inclined to the ecliptic several degrees, for which reason they can never be seen upon the Sun, excepting when they are either in, or very near to one of their nodes at the time of their being in inferior conjunction with the Sun. If they are exactly in their node at the time of the conjunction taking place, they will appear to pass over the centre of the solar disc; if their geocentric latitude at the time be any thing less than the semidiameter of the Sun's disc, they will be seen to traverse some portion of his upper or lower limb, according as their geocentric latitude is north or south; if their latitude be equal to the semidiameter of the Sun, they will just touch the limb of the Sun, but without entering it or obscuring any part of it; and if their geocentric latitude exceed the semidiameter of the solar disc, they will pass either above or below the Sun and be invisible, having their enlightened side turned entirely away from the Earth in the manner already described.

The apparent motion of an inferior planet across the disc of the Sun is called a transit, and from the above observations, it is evident that these phenomena can very seldom take place; when they do happen, they cannot fail, from the rarity of their occurrence, to prove highly interesting to Astronomers, and as the transits of Venus afford an easy

method of enabling them to determine the distance of the Sun from the Earth, these phenomena may be considered among the most important the science of Astronomy has to boast. As, however, this mode of ascertaining the distance of the Sun consists in finding the parallax of that luminary by the transit of Venus over his disc, it will be proper in this place to enter a little into the subject of parallax, or the difference in the place of a planet as seen from the centre, and from a point on the surface of the Earth.

Let A B, fig. 24, be the Earth, C its centre, H a point in the rational horizon, A the place of a spectator. Z the zenith of the place A, and D E F G four different positions of a planet or any other heavenly body; also, let Z I H represent an arc of the starry heavens, comprehended between the horizon and the zenith; when the planet is at D, it will appear in the horizon at H to a spectator at the Earth's centre, but to the spectator at A, on the surface of the Earth, the planet will appear at *h* below the horizon, H being the true and *h* the visible or apparent place of the planet; the parallax of the planet D, will therefore be measured by the arch H *h* of the heavens, or by the angle H D *h*, which is equal to the angle A D C. When the planet is above the horizon at E, its true place visible from the Earth's centre is P, and its apparent place *p*; its parallax, therefore, will be P *p*. In like manner, when the planet is at F, its parallax will be R *r*, and when the planet is at G, or in the zenith, it will have no parallax, being seen in the same point of the heavens, as viewed either from the centre or the surface of the Earth. The parallax of any object, therefore, is the greatest when in the horizon, decreases as the altitude increases, and altogether disappears when the

object is in the zenith, because its true and apparent places then coincide.

The effect of parallax is to diminish the altitude of any celestial phenomenon, or to make it appear nearer the horizon than it really is, hence it is called the parallax of altitude. As, however, this change of the altitude by parallax, may, according to the different situation of the ecliptic and equator to the horizon, also produce a change in the longitude, latitude, right ascension, and declination of the phenomenon, there will also be a parallax in longitude, a parallax in latitude, a parallax in right ascension, and a parallax in declination; thus, the parallax diminishes the longitude in the western part, and increases it in the eastern; diminishes the northern latitude and declination in the eastern part, and increases them in the western, but increases the southern both in the eastern and western part; increases the right ascension, and diminishes the descension. Hence it appears that the parallax has just the contrary effects of refraction, and consequently without a knowledge of the parallax of any body, it would be impossible to make the necessary correction for determining its true place in the heavens. The doctrine of parallax, however, derives its greatest importance from its affording us the means of calculating the distances of the heavenly bodies, for if the horizontal parallax of any heavenly body or the angle D of the triangle A D C be known, the side C D, which is the radius of the Earth, being already known, the distance of the body from the Earth's centre may be ascertained by a common problem in trigonometry.

The parallax of an object is evidently the same as the angle which the distance between the Earth's centre and a given point on its surface subtends at

the object; hence it appears that the farther the object is distant from the Earth, the less will be its parallax; thus, the parallax of the planet X is only H x, which is less than H h, the parallax of the planet D. As, therefore, the parallax of an object depends on the distance of that object from the Earth, it is easy to conceive that this distance may be so great as to render the parallactic angle insensible, in which case the object will have no parallax, and consequently will be seen from all parts of the Earth in the same position: thus, the fixed stars are so remote as to have no sensible parallax, and even the Sun and all the primary planets except Mars and Venus when in perigee, are so far from the Earth, that their parallax is too small to be easily detected. The very great importance, however, of the horizontal parallax in determining the distances of the heavenly bodies with accuracy, has induced Astronomers to invent several methods for obtaining the horizontal parallax of the Sun and planets. It would, however, be entirely foreign to the object of these lectures, to enter into a minute detail of the various methods which have been proposed for this purpose. The easiest method of determining the parallax of a planet is by observing its zenith distance, and its relative position to a fixed star at two places on the Earth's surface nearly under the same meridian, but very remote from each other.[1] In the case of the Sun, however, the parallax is so small on account of the immense distance of that luminary from the Earth,

[1] As the sum of the sines of the two zeniths' distances (if the observers be on different sides of the equator) or their difference (if on the same side) is to radius, so is the difference of the two angular distances of the planets from the fixed star, to the planet's horizontal parallax.

that it can only be accurately determined from the transits of Venus.

The method of finding the parallax of the Sun from the transits of Venus over his disc was first suggested by Dr. Halley, who, in the year 1691, presented to the Royal Society a dissertation upon that subject with an account of the particular times when such transits would take place. This mode of finding the parallax of the Sun was recommended by the Doctor with all that earnestness which the importance of the subject required, and according to his suggestions several Astronomers were dispatched to different parts of the globe for the purpose of observing the transit of Venus in 1761, and also that of 1769. From these observations, which were conducted with the greatest care, the distances and magnitudes of the Sun and planets have been more accurately determined than by any method previously adopted for that purpose.

The general principles of this important and abstruse operation may be thus explained: The apparent magnitude of the Sun and the periodic time of Venus being known, the time that she employs in moving over the Sun's disc may be easily calculated, and is the same as would be observed by a spectator at rest at the Earth's centre. The duration of these transits, as seen from different parts of the Earth, differ from each other, and also from the calculated time; and this difference between the true and observed duration of a transit, obviously arises from, and will be in direct proportion to the parallax of Venus, for the nearer Venus is to the Earth the greater is her parallax, and consequently, so much the more will the true duration of her transit be contracted. By observing, therefore, at places adapted to the purpose, how much the duration of the transit is less

than its true duration calculated for the Earth's centre, the parallax of Venus will be ascertained, whence, by analogy, the parallax and distance of the Sun and of all the planets from him may be readily found. This will be understood from fig. 25. in which, let S be the Sun, A D B the Earth, C its centre, and V Venus, revolving in her orbit in the direction *a* V *b*. The Earth's motion on its axis being in the direction B D A, contrary to the motion of Venus in her orbit, the motion of Venus across the disc of the Sun in the path *v v′ v″* will be accelerated in consequence of the observer being carried by the Earth's rotation in the contrary direction B D A, and therefore the transit will be of a shorter duration than it would be if viewed from the centre C of the Earth, or from any point of the Earth at rest; for were Venus even to remain stationary, and the Earth to have no other motion but that of its diurnal rotation, it is clear that the planet Venus would appear to move across the solar disc. When the observer is at B, Venus will appear like a black spot upon the Sun at *v*; when the observer has arrived at D, Venus will appear at *v′*, and when he has got to A, Venus will appear at *v″*. But the motion of Venus in her orbit will also cause her to appear to move across the Sun's disc in the path *v v′ v″*, and, consequently, that motion must be considerably accelerated by the diurnal motion of the Earth, causing a contraction of the transit which must evidently increase with the proximity of Venus to the Earth, and it is therefore proportional to her horizontal parallax. By observing, therefore, at proper places on the Earth, how much the duration of the transit is diminished, or by finding the difference between the observed time of the transit and its calculated time as seen from the centre of

the Earth, the parallax of Venus and that of the Sun may be ascertained.

Another method of finding the Sun's horizontal is as follows: let A B D, fig. 26. be the Earth, V, Venus, and R S T, the eastern limb of the Sun. To a spectator at B, the point x of that limb will be on the meridian, and will be referred to the point E in the heavens: Venus appearing just within the limb of the Sun at S. But at the same instant, to a spectator at A, Venus is east of the Sun in the line A V F, and if she were then visible, would appear in the heavens at F: while the point x of the Sun's limb is referred to e. The horizontal parallax of Venus is C V A, and is equal to the opposite angle F V E, which is measured by the arch F E. C S A is the Sun's horizontal parallax, equal to the opposite angle e S E, whose measure is the arch e E. Now, the angle C V A, the horizontal parallax of Venus, may be readily found by observing the difference between the ingress of Venus upon the Sun's limb, as seen from A and B, or the time she takes to move from V to v, the allowance being made for the difference of the meridians A B. The horizontal parallax of Venus being found, the Sun's horizontal parallax may be easily ascertained, for C V A the horizontal parallax of Venus, is to C S A, the Sun's horizontal parallax, as S C is to V C, the ratio of which is known, and the horizontal parallax of Venus being found, we have $\frac{CVA \times VC}{SC} =$ the Sun's horizontal parallax C S A.

From a great number of observations, made with every possible degree of accuracy, upon the transit of Venus in the year 1769, in different parts of the world, the Sun's parallax has been found to be 8″. 73, whence, by a simple operation

in trigonometry, his distance from the Earth is found to be in round numbers, 95 millions of miles.

The distance of the Sun from the Earth having been ascertained, the distances of the other planets from the Sun may be deduced from the third law of Kepler by the following proportion: — As the square of the Earth's period round the Sun is to the cube of its mean distance, so is the square of the period of any other planet to a fourth proportional, the cube root of which will be the distance of that planet from the Sun.

The distances of the Sun and planets being known; from their apparent diameters at those known distances, their true diameters and magnitudes may be ascertained.

LECTURE XII.

PHENOMENA CONNECTED WITH THE PLANET WE INHABIT, AS VIEWED BY A SPECTATOR ON ITS SURFACE. — OF THE ABERRATION OF LIGHT. — OF THE PRECESSION OF THE EQUINOXES AND THE NUTATION OF THE EARTH'S AXIS.

At the distance of about 95 millions of miles from the centre of the system, in a happy medium between the proximity of the inferior planets to, and the remoteness of the superior planets from, the Sun, is placed the Earth, the planet on which we ourselves reside, and which, on this account, cannot fail to become an object of peculiar interest to us who inhabit it.

The apparent diurnal and annual revolutions of the Sun we have already shown to result from the motions of our own globe, the former being caused by the rotation of the Earth about its axis, once in 23 hours 56 minutes 3·4 seconds, and the latter, by its annual motion round the Sun, performed in about 365 days 6 hours. We have also seen that the Earth is of a spheroidal form, that its orbit is of an elliptical figure, and that these circumstances (which are common to all the planets of the system) are the natural effects of a centrifugal force combined with the power of attraction; and we have contemplated this globe (while explaining the phenomena of the Sun as seen by a spectator on the Earth's surface) as undergoing the vicissitudes of day and night, and experiencing the regular returns and orderly succession of the seasons.

I shall, therefore, in the next place, proceed to describe those phenomena connected with our planet, which have not hitherto come under our consideration.

The aberration of light is a phenomenon arising from the progressive motion of that fluid, and the annual motion of the Earth in its orbit. For the discovery of this phenomenon we are indebted to Dr. Bradley, who was led to it by the result of observations made for the purpose of determining the annual parallax of some of the fixed stars, or the apparent change of place in the heavens to which it was supposed by Astronomers the fixed stars would be subject when viewed from the Earth in two opposite points of its orbit; in other words, to find the angle subtended by the diameter of the Earth's orbit at the fixed stars.

The only objection of any very considerable weight that could be urged against the Copernican view of the Earth's annual motion round the Sun, and which was eagerly laid hold on by the opponents of the Copernican system, was, that if the Earth describes an orbit round the Sun, whose diameter is nearly two hundred millions of miles, it follows that, if the axis (which always preserves its parallelism through every part of its revolution) in any part of its orbit be directed to a particular point in the heavens, it ought, in six months from that time, to be directed to another point, two hundred millions of miles distant from the former, which is quite contrary to what is found by observation to be the case. Now, although the legitimate answer to this objection, as proved by repeated experiments, is, that the distance of the nearest fixed star is so immensely great, that the orbit of the Earth viewed from it becomes only a point, and consequently does not subtend any sen-

sible angle, yet, as the discovery of such a parallax would satisfactorily demonstrate the truth of the Copernican system, and would besides, if the quantity of the annual parallax of any of the fixed stars could be ascertained, enable us with ease to determine the distance of those stars from the Earth, this enquiry must, on both these accounts, be particularly deserving our attention; and it has accordingly been pursued by Astronomers with the utmost diligence, and it was while engaged in making observations for this purpose that Dr. Bradley discovered a variation in the position of the stars, called their Aberration, which could neither arise from parallax nor from the nutation of the Earth's axis (hereafter to be explained).

As the aberration of light is a subject of considerable importance, a few particulars relative to its discovery, may, perhaps, be found interesting. On the 3d December, 1725, the Hon. Samuel Molyneux, Esq. assisted by Dr. Bradley, with an instrument constructed by Mr. Graham, upon the accuracy of which they could depend, fixed perpendicularly, began to observe the bright star γ in the head of Draco, as it passed near the zenith, and carefully took its situation, noting the time of the observation. This process was repeated on the 5th, 11th, and 12th days of that month, without any change in its distance from the zenith at the time of its passing over the meridian being perceived, but on the 17th of the same month, it passed a little more southerly; on the 20th, they repeated their observations, and found that it was removed still more southerly, and so continued to transit the meridian more and more southerly, till about the beginning of March, 1726, when it had arrived at its most southern limit, and was found to pass over the meridian, 20″ more southerly

than at the time of their first observation on the 3d December, 1725. Its distance from the zenith appeared to remain the same till about the middle of April, when they first perceived it to be returning back towards the north. About the beginning of June, it passed the meridian at the same distance from the zenith as it had done in December, and from that time it continued to transit the meridian more and more northerly each succeeding day till September following, when it again became stationary, being 20 seconds more northerly than in June, and 39 seconds more northerly than in March. From September it returned towards the south, and in December it again arrived at the same situation in which it was observed twelve months before, allowance being made for its difference of declination arising from the precession of the equinoxes. As the change of position observed in this star was not in the direction that it ought to have been if caused by parallax, it became a matter of difficulty to the observers to account for so singular a phenomenon, and the death of Mr. Molyneux occurred before its true cause was discovered. After that event, however, Dr. Bradley, in the year 1727, began a similar course of observations at Wanstead, in Essex, where, not having convenience for the use of so long a telescope as that of Mr. Molyneux, the length of which was upwards of 24 feet, he made use of another instrument of 12½ feet, made also by Mr. Graham, and after twelve months observations, during which he found the same appearances to take place, not only in that, but also in several other stars, and being fully satisfied of the correctness of his instrument, he conjectured the aberration or change of place in the stars to arise from the progressive motion of light combined with the annual motion of the

Earth in its orbit, a conjecture which all succeeding observations have tended to confirm, and thus, in the year 1728, was completed a discovery which fully demonstrates the motion of the Earth round the Sun, and confirms, at the same time, the truth of Roemer's deduction of the successive propagation of light from the eclipses of Jupiter's satellites.

Having thus detailed the progress of this important discovery, I shall proceed to explain the phenomenon itself: — If the eye of a spectator viewing a star or any other object be at rest, or if it be in motion, provided the direction of its motion be in a straight line either directly towards or directly from that object, its apparent place will obviously continue the same, but if the motion of the eye be in any other direction, and if the motion of the light emitted by the object be not instantaneous but progressive, the apparent place of the object will undergo a change exactly proportioned to the combination of the motion of the eye with the motion of light. To understand this, let B C, fig. 27, be a ray of light emitted by a star at B, and falling perpendicularly upon the line A C; the apparent place of the star will continue the same whether the eye be at rest at C, or whether it advance towards or recede from the star in the direction of the right line B C, which in all these cases will be the visual line, and this, whether light be propagated in time or instantaneously. If, however, the motion of the eye be in any other direction, as A C, and light be propagated in time with a certain velocity, which, for example, let us suppose to be in such a ratio to the velocity of the eye, or, which is the same thing, to the velocity of the Earth in its orbit, that a particle of light passes from B to C, in the same time that the Earth

moves from A to C, then that particle of light by which the star is seen when the Earth is at C, must have been at B when the Earth was at A, and by the composition of the two motions, the particle of light will seem to describe the line B A or D C instead of its real course B C, and will appear in the direction A B or C D instead of its true direction C B. Now, let A B represent a tube carried with a parallel motion along the line A C in a given portion of time; as, for example, four minutes, and let us suppose that a particle of light would move through the space B C in the same time; and, that when the tube is in the position A B, a particle of light enters at B, then, at the end of the first minute, the tube having passed over one-fourth part of the line A C, will be brought into the position *a b*, while the particle of light, having also travelled through one-fourth of the line B C, will be in the axis of the tube at *g*; at the end of the second minute the tube will be in the situation *c d*, and the particle of light will arrive at *h*, still in the axis of the tube; at the end of the third minute, the tube will have the situation *e f*, and the particle of light will arrive at *i*; finally, at the end of the fourth minute, the particle of light will arrive at the eye or point C, the tube being in the situation C D, and consequently the star which is really at B will appear at D, B C D or A B C being the quantity of the aberration.

This phenomenon admits of a very familiar illustration by supposing a shower of hail to fall during a perfect calm, and consequently quite perpendicularly. Now, in order that a hailstone may pass freely through a long tube at rest without touching either side, it is obvious that the tube must be held in a perpendicular direction; but if the tube be moved forward while it retains its

perpendicular direction, the hailstones which enter the tube, instead of passing directly through it, will all strike the hindmost side of the interior of the tube; in order, therefore, that the hail may be made to pass freely through the tube, it will be necessary to incline it forwards at such an angle as may compensate for its motion, and it is easy to prove that the degree of inclination requisite to be given to it must depend upon the relative proportion of the velocity with which the hail descends, and that of the motion of the tube; thus, if the volocity of the hail and of the tube be supposed equal, the angle of inclination must be exactly forty-five degrees, but if the velocity of the hail exceed that of the tube, the inclination of the latter must be less, and *vice versâ*.

Now, in applying the foregoing illustration to the progress of light as compared with the motion of the Earth in its orbit, it is to be observed, that as the velocity of light is above 10,300 times greater than that of the Earth, the angle of inclination of the tube, in order to allow the light to pass through it, can only be about 20 seconds, and consequently the aberration of the stars near the pole of the ecliptic, and whose light strikes the Earth almost perpendicularly, ought always to be about 20 seconds, that is, those stars ought never to be seen in their true place, but always about 20 seconds of a degree on one side or other of it; in other words, they ought to describe a small circle about their true place, the radius of which is 20 seconds, and this is precisely what Dr. Bradley found by observation to be the case, as has been already detailed.

Since it is only those stars which are near the pole of the ecliptic, the direction of whose light is always at right angles to the motion of the Earth

in every part of its orbit, it is obvious from what has now been said, that it is only in those stars that the full effect of aberration can be seen. Those stars which are situated near the ecliptic will have the motion of the Earth twice in a year, nearly in the direction of their light for a few days, and will therefore be subject to no aberration during those periods: it will also be twice in a year at right angles to their light, but the motion being in opposite directions, the stars will appear at those times to be 20 seconds from their true place, but on opposite sides of it; at all other times the Earth moving intermediately between those extremes, the apparent places of the stars will be at intermediate distances from their true places, but will never exceed 20 seconds; hence a star in the ecliptic appears to be in a state of oscillation about its true place, its distance from which, however, never exceeds 20 seconds, and those stars which are situated between the ecliptic and its pole, will describe small ellipses, the eccentricity of which will vary according to their latitude.

The places of the planets are also effected by the progressive motion of light combined with the annual motion of the Earth. The aberration of a planet being equal to its geocentric motion, during the time that light employs in passing from the planet to the Earth. The aberration of the Sun is always 20 seconds, which is the space moved through by the Sun, or rather by the Earth, in eight minutes and seven seconds, the time that light takes in passing from the Sun to the Earth; hence the aberration of the other planets may be easily ascertained by the following proportion: as the distance from the Earth to the Sun is to the distance of the planet, so is 8′ 7″ to the time of light's passing from the planet to the Earth; then

the geocentric motion of the planet in this time will be its aberration, whether it be in longitude, latitude, right-ascension, or declination. This will be greatest in longitude, and being equal to the planet's geocentric motion, will, of course, vary with that motion. It will be least when the planet is stationary, and greatest in the superior planets when they are in opposition, but in the inferior, the aberration is greatest at the time of their superior conjunction. The aberration of the planets, therefore, vary in longitude according to their situations, but that of the Sun is, as before observed, a constant quantity, being always 20 seconds; he may, however, alter his declination, by a quantity varying from 0 to 8 seconds, being the greatest about the equinoxes, and vanishing in the solstices. The aberration of the planets in latitude is so trifling, on account of their orbits being very little inclined to the ecliptic, that it may be safely neglected. Their aberration in right-ascension and declination are more considerable, depending on their situation in the zodiac.

It has been already observed that the Earth is flattened at the poles, and swelled out at the equator, whence it assumes the form of an oblute spheroid. By the joint action of the Sun and Moon upon the protuberant parts of this spheroid, or the equatorial regions of the Earth, a phenomenon is produced, called the Precession of the Equinoxes, being a slow and almost imperceptible motion, by which the equinoxes change their places, going backward or westward on the ecliptic contrary to the order of the signs.

In order to understand this phenomenon, it must be recollected that the equinoctial is a great circle in the heavens, coinciding with the terrestrial equator, and inclined 23° 28′ to the ecliptic. If,

therefore, the Earth's equator constantly retained the same invariable position, the equinoctial would likewise constantly pass over the same fixed stars, and would cut the ecliptic (which is an invariable circle) in the same points. But it has been observed, that the Sun and Moon acting obliquely upon the redundant matter at the equator, draw it continually towards the ecliptic, causing the equinoctial points to recede upon that circle at the rate of about 50¼ seconds in a year; in consequence of which recession, the longitudes of all the stars (their places on the ecliptic being reckoned from the vernal equinox) will increase 50¼ seconds every year. This in one year is but a very trifling change, but the accumulation of it after a number of years, becomes too important to be allowed to pass unnoticed, and it is by this precession of the equinoxes, as has been observed upon a former occasion, that the constellations, which, in the time of Hipparchus, corresponded with those signs of the ecliptic which bear their name, are now so far removed from the situation they then occupied, that the equinoctial points which in his time were fixed to the first star of Aries and Libra, are now carried backwards into Pisces and Virgo. The equinoctial points make a complete revolution in something less than 26,000 years, the poles of which must consequently describe a circle round the poles of the ecliptic, whose diameter is about 47 degrees, being equal to twice the inclination of the ecliptic to the equator. The annual precession being, as above described, about 50¼ seconds, it is evident, that if the celestial equator cut the ecliptic in a particular point, on any day of this or any other year, it will, on the same day of the year following, cut it in a point 50¼ seconds to the west of its former intersection; if, therefore, the

Sun set out from one of the equinoctial points, he will arrive at the same equinoctial point again something before he has performed a complete revolution in the heavens, for the equinoctial point from which he set out, has, as it were, retreated 50¼ seconds to meet the Sun: hence the Sun's arrival at that point *precedes* his arrival at the same fixed spot in the heavens from which he set out the year before, by 20′ 23″ of time, or by an arc of 50¼ seconds. This revolution of the Sun from one equinox to the same again, is called the Tropical or Solar year, and is that upon which the seasons depend. The time in which the Sun revolves from any fixed star to the same fixed star again, is called a Sidereal year, and is the true time in which he performs a complete revolution in the heavens: the difference, therefore, between a tropical and sidereal year is 20 minutes 23 seconds, the former being performed in 365 days, 5 hours, 48 minutes, 49 seconds, and the latter in 365 days, 6 hours, 9 minutes, 12 seconds. All the other planets will, in like manner, have a solar and sidereal revolution in their respective orbits.

It has been remarked, that the precession of the equinoxes is caused by the joint action of the Sun and Moon upon the equatorial regions of our Earth. In producing this phenomenon, the effect of the Moon greatly exceeds that of the Sun, for although the magnitude of the Sun so far surpasses that of the Moon, yet, the proximity of the latter to our own globe more than compensates for the excess of magnitude in the former, and it is found, that of the whole precession, very little more than 15 seconds is produced by the attraction of the Sun, while that of the Moon exceeds 35 seconds; there is, however, an inequality in the part of the precession produced by the action of the Moon,

caused by the perpetual change in the position of her nodes, and in the inclination of her orbit to the Earth's equator. To these causes, also, is to be principally attributed an apparent motion in the fixed stars, resulting from the real motion of the Earth's axis called its nutation. By this motion it describes from east to west a small ellipse in the heavens, whose diameters are 19·1 seconds, and 14·2 seconds, and its period which corresponds to that of the revolution of the Moon's nodes is 18 years. One of the most important effects of this nutation is the change produced by it, together with the precession of the equinoxes in the obliquity of the ecliptic. This change is computed for different times of the year, and set down in the ephemeris. For the discovery of the nutation of the Earth's axis, like that of the aberration of light, we are indebted to the industry and ingenuity of Dr. Bradley.

The orbits of all the other planets being inclined to the Earth's equator, the action of those bodies upon the protuberant matter about the equator, must also have a tendency to diminish the obliquity of the ecliptic, and also to produce a precession in the equinoctial points. Their effects, however, are almost insensible, the diminution of the obliquity arising from the united action of all the planets not exceeding 50 seconds in a century, and the corresponding precession amounts only to about 18½ seconds.

LECTURE XIII.

PHENOMENA CONNECTED WITH THE GLOBE WE INHABIT, AS VIEWED FROM ITS SURFACE, CONCLUDED. — OF LATITUDE AND LONGITUDE. — HOW TO FIND THE LATITUDE AND LONGITUDE OF A PLACE. — MENSURATION AND MAGNITUDE OF THE EARTH. — OF CLIMATES. — OF ZONES. — NAMES ASSIGNED TO THE INHABITANTS OF THE EARTH FROM THEIR SHADOWS AND THEIR DIFFERENT SITUATIONS ON THE GLOBE.

HAVING, in the course of our investigations, become acquainted with the true figure and motions of the Earth, we may, in the next place, proceed to enquire in what manner the relative situation of different places upon its surface is ascertained; and the assistance astronomy affords us in determining this problem, may be considered one of the most important advantages mankind derive from the cultivation of this useful and interesting science.

In determining the situation of any particular place, it became necessary, in the first instance, to have some fixed points of reference from which its distance was to be reckoned, and the equator, every part of which is just 90° from each of the poles, seems to have been selected by common consent, for this purpose, the meridional distance of any place from this circle being called its latitude; but the choice of a first meridian, or that from which

the distance of the place in a contrary direction (commonly called its longitude) was to be reckoned, appears to have been a matter not so easily decided, no place having been found whose natural claims to this distinction, were sufficiently powerful to obtain the universal suffrage of all nations in its favour. Most of the ancient Greek geographers made the first meridian to pass through Hera or Junonia, one of the Fortunate Islands, as they were then called, which is supposed to be the present island of Teneriffe, one of the Canaries, from which the longitude was reckoned eastwards: western longitude being totally disregarded, if not wholly unknown before the discovery of America. Some have reckoned their longitude from the meridian passing through St. Nicholas, one of the Cape Verd islands. Others have made choice of the meridian passing through the island of Corvo, the most northerly of the Azores, because the magnetic needle at that time was there found to point due north; and as the variation of the needle, being itself subject to a variation, was not then known, this was thought to be a sufficient reason for the preference. The meridian of Ferro, one of the most westerly of the Canaries, seems, however, to have been more generally adopted, but the method usually practised by modern geographers, is to assume the meridian of the capital city, or principal observatory of their own nation, as a first meridian, and thence to reckon the longitudes of all other places on the globe, or their distances east or west, from that meridian. Thus, the English reckon their longitude from the meridian of Greenwich; the French from that of Paris, and so of the rest.

When we speak of the latitude[1] and longi-

[1] From *latitudo*, breadth.

tude[1] of any place, we commonly mean no more than to express the distance of that place, considered simply as a point on the Earth's surface, from the equator, and from the first meridian; this is, therefore, an evident solecism, since a point can have neither breadth nor length, which is the true meaning of these words. A single instance will suffice to show that this method of expressing the situation of places, involves a misapplication of terms, which long usage, though it may induce us to tolerate, can never justify. We commonly say the latitude of London is 51½°, and its longitude 0, which is neither more nor less than asserting (if these words be allowed their true meaning) that London is 3090 geographical miles in breadth, without any such thing as length, where the absurdity of reducing London to a mathematical line is considerably heightened by denying to that line the dimension of length, which, in fact, constitutes its very essence; thereby leaving us room to prove, without any great exertion of our logical powers, that London is either a square, the side of which is 3090 geographical miles, or a mere physical point, without extension of any kind. The misapplication of these words by modern writers requires more particularly to be pointed out, since they frequently occur among old geographers in their proper sense; thus, when they speak of the longitude and latitude of any country, &c. they commonly mean the actual length and breadth of that country or place, and it seems highly probable that these terms were originally applied to the

[1] From *longitudo*, length. We have had frequent occasion to use these words, but their derivation was purposely delayed to this place, where it so immediately concerns the subject about to be discussed.

Earth itself, rather than to any particular place or places on its surface; for the meridional distance of any place being measured on a semicircle, extending only from pole to pole, this might very properly be termed the latitude or breadth of the globe, while the line, measuring the extent of the globe in the contrary direction, being a whole uninterrupted circle, would be very naturally denominated its longitude or length. Some, indeed, account for the introduction of these words by supposing that a greater portion of the Earth being known to the ancients eastward and westward, than towards the poles, they called the former its length, and the latter its breadth. However this may be, the present misapplication of these words cannot fail to be a matter of regret; yet, as some respect is due to a long established custom (however erroneous), I shall content myself with having pointed out the different senses of these two words, and distinguished the true from the false, concluding my observations upon this subject in the words of Varenius "In my judgment, it were better not to "use the words latitude and longitude, but only "distance from the equator, and from the first "meridian: but being so long used, they cannot "now be abolished, and we shall use them here-"after in this sense."[1]

Having shown from what points the distances of places upon the Earth's surface, commonly called their latitudes and longitudes, are reckoned, I shall proceed to explain the manner in which these particulars may be ascertained.

The latitude of any place may be found either by night or by day, without much difficulty in the former case, by taking the altitude of the pole-star,

[1] Varen. Geog. Vol. ii. p. 671.

and in the latter, by observing the meridian altitude of the Sun. It has been already remarked, that an observer any where on the equator will have both the celestial poles in his horizon, and that to an observer at either of the poles of the Earth, the poles of the world are in his zenith and nadir.[1] At the equator, therefore, the pole-star has no altitude, but as we travel from the equator northwards, this star appears to ascend above the horizon, and gradually rises higher and higher the nearer we approach the pole, where its altitude would be 90°, and consequently, the height of the pole star increasing with the distance of the spectator from the equator, becomes a measure of that distance, or of the latitude of the place. This will be understood from fig. 28, in which, let *h z o n* represent the Earth, *n s* its axis, *e q* the equator, *z* the place of the observer, and *o n* the elevation of the pole; also let H Z O be an arc of the heavens, Z the zenith of the place *z*, E the celestial equator, H *h o* O the horizon, N the pole-star, and N O its altitude or height above the horizon, coinciding with *n o* the elevation of the pole. Now Z O, the distance from the zenith to the horizon, or the corresponding arc *z o* of the terrestrial meridian, is 90°; E N, the distance of the equinoctial from the pole-star, or its corresponding arc *e n*, is also 90°; and Z N or *z n* is common to these two equal quantities, and may, therefore, be taken from both, and the remainders E Z and N O or *e z* and *n o* will be equal: but *e z* is the distance of the observer from the equator, and *n o* is the elevation of the pole with which N O, the altitude of the pole-star, corresponds; therefore, the elevation of the pole, or the altitude of the pole-star, is

[1] See Lect. vii, p. 114, 115

equal to the latitude of the place. We have, in this example, considered the pole-star as situated exactly in the pole of the heavens; as, however, this is not the case, we may obtain the height of the true pole by measuring the altitude of any other circumpolar star, more distant from the pole at its greatest and least elevation, or when it passes the meridian above and below the pole, half the sum of these two altitudes, corrected by refraction, will be the true height of the pole, or the latitude of the place. Thus, if *a* O be the altitude of the circumpolar star when above the pole, and *b* O its altitude when on the meridian below the pole, then N O, the true altitude of the pole, is obviously an arithmetical mean between these two altitudes.

The method of finding the latitude by the meridian altitude of the Sun is very simple, and being upon the whole less liable to error than the foregoing, is more frequently resorted to. It is to be observed, that the altitude of the pole, the distance of the pole from the equator, and the height of the equator together, make two right angles, or 180°. The distance of the pole from the equator is always one right angle, or 90°, and consequently the distance of the pole from the horizon, and the height of the equator, must together make up the other right angle, or 90°, being mutually the complements of each other. But the altitude of the pole we have seen is always equal to the latitude of the place, and therefore if we can find the height of the equator by taking this from 90°, we shall obtain the latitude of the place. Now the height of the equator may be ascertained by observing the meridian altitude of the Sun on any day, and subtracting from it the Sun's declination for that day, if the Sun be north of the equator, or adding to it

the Sun's declination, if he be south of it. The difference or sum of these numbers will be the height of the equator or colatitude of the place. The latitude of a place may, in like manner, be obtained by taking the meridian altitude of any of the planets or fixed stars whose declinations are known, allowance being made for refraction and parallax when the meridian altitude of a planet is made use of, and for refraction when that of the fixed stars is employed.

In describing the methods employed for ascertaining the longitude, it will be necessary to recur to a few circumstances which have been already taken notice of.[1] It has been observed, that the time which elapses between the arrival of the Sun at any particular meridian, and his next subsequent arrival at the same meridian, is called a natural day, and is, in fact, the time in which, by the rotation of the Earth from west to east on its axis, any particular meridian is carried round from the Sun to the Sun again; now, since this revolution is performed in twenty-four hours, and the equator is divided into 360°, it is obvious that there must be a revolution of 15° of the equator in one hour of time, and that these two correspond to each other; consequently, when it is 12 o'clock at any particular place, it will be 1 o'clock at all places 15° eastward of it, and 11 o'clock at all places 15° west of it, the time at any place being determined by the Sun's arrival at the meridian of that place; and as the Sun's apparent diurnal revolution is performed from east to west, all places lying to the east, will have their day farther advanced, or the hour will be later, while all places which lie to the west, will have their day less ad-

[1] See Lecture viii. p. 123.

vanced, and the hour shown by their clocks will of course be earlier. If, therefore, the difference of time between any two places be found, their difference of longitude may be ascertained by merely converting this difference of time into degrees, minutes, &c. allowing 15° of longitude to one hour of time, one degree to four minutes of time, and so on. Now, since the English geographers reckon their longitude from the meridian of Greenwich, if a chronometer be well regulated and set to the time at Greenwich, it will show the Greenwich time in all places to which it is carried; and the time at any distant place of which the longitude is sought, may be found by observing the time of the Sun's passing the meridian, to which the equation of time being applied, will give 12 o'clock or noon at that place; the difference between this and the time shown by the chronometer, converted into degrees, &c. will give the longitude of the place from Greenwich. Thus, if at some place, the longitude of which I wish to discover, I observe the time of the Sun's passing the meridian, and find by the chronometer that at the same instant it is no more than three quarters past eight in the morning at Greenwich, this difference of time between these two places, viz. three hours and fifteen minutes being converted into degrees, &c. gives 48 degrees 45 minutes for the longitude of the place, which is east, because the time is forwarder or later than that of Greenwich. Now this method is obviously the most simple, and would be the most correct, which could be employed for determining the longitude, provided that a chronometer could be made which might be depended upon under every change of climate; this, however, has been found impracticable, and although much has been done towards accomplishing this desirable

object, yet no chronometer has hitherto been made, which, even in the same place, will always go quite correctly. To remedy, as far as possible, the errors to which a chronometer is liable, its mean rate of going is usually determined by observing, for some time before it is sent out, its daily loss or gain, and taking a mean of these observations; but as the rate of going of a watch, however correctly made, is apt to vary from the difference of temperature of different climates, &c. other methods have been resorted to for ascertaining the difference of time at any two places.

These methods are purely astronomical, and depend upon having the exact times of certain celestial phenomena, calculated for any particular meridian, and set down in an almanac or ephemeris adapted to that meridian, so that if when any of these phenomena are observed in any distant place, the time at that place be known, the difference between this time and that at which the same phenomenon was calculated to take place, and set down in the almanac, will also be known, and consequently the longitude may be readily found. Thus the Nautical Almanac which is published several years in advance, for the advantage of ships going long voyages, contains for every day the computed times of all the most remarkable celestial phenomena, adapted to the meridian of the royal observatory at Greenwich.

The phenomena proper for determining the longitude are the eclipses of Jupiter's satellites; the eclipses of the Moon, the Moon's place in the zodiac, and the Moon's distances from the Sun or certain fixed stars, which, from their use in determining the longitude at sea, are sometimes called nautical stars. Each of these methods is, however, liable to peculiar objections.

The phenomena of Jupiter's satellites are in some respects preferable to those of the Moon for finding the longitude, being less liable to parallaxes, and affording a very commodious observation whenever the planet is above the horizon, but being invisible to the naked eye, they must always be observed by the assistance of a telescope, the use of which is very difficult at sea, when accurate observations are required.

Eclipses of the Moon occur too seldom to be of much general use in ascertaining the longitude, and as the beginning or end of an eclipse of the Moon cannot usually be determined nearer than one, and sometimes two or three minutes of time, the longitude cannot be obtained by this method to any very great degree of accuracy.

The Moon's place in the zodiac, although a phenomenon more frequently to be observed than her eclipses, yet, by reason of two parallaxes, the calculus is rendered too perplexed and intricate to be generally practicable.

The Moon's distance from the Sun and from certain fixed stars are phenomena which by the frequency of their occurrence, seem to be better calculated for this purpose than any other, since the longitude of a ship may be thereby determined at almost any time. The chief error to which this method of ascertaining the longitude is liable, arises from inaccuracy in taking the angles; the best way, therefore, is to make several observations upon different stars, by which means the errors in a certain degree correct one another.

Having seen in what manner the latitudes and longitudes of places may be found, and consequently their particular situations and relative positions upon the surface of the Earth ascertained; our next enquiries will naturally be directed to the

manner in which the magnitude of the Earth may be determined. This is a problem which has engaged the attention of astronomers and mathematicians ever since the sphericity of the Earth was discovered. Anaximander, a disciple of Thales, who lived about 550 years before Christ, is mentioned by Diogenes Laertius as the first among the Greeks who gave an account of the circumference of the Earth, and his measure appears to have been adopted by succeeding mathematicians till the time of Eratosthenes; and it is generally supposed that it is to this measure that Aristotle alludes at the end of lib. 2, De Cœlo, when he says, that mathematicians who have attempted to measure the circuit of the Earth, make it four hundred thousand stadia. Of the method employed by Anaximander no account has reached us, but with regard to that of Eratosthenes, who lived about two hundred years before Christ, we are better informed. He had observed that the bottom of a deep well, at Syene, a town of Egypt, situated on the right bank of the Nile, under the tropic of Cancer, was completely enlightened by the rays of the Sun when on the meridian of that place, on the day of the summer solstice, and on the same day, he found the zenith distance of the Sun at Alexandria (which he supposed to be on the same meridian) to be 7° 12′, or a 50th part of the circumference of a great circle in the heavens. Concluding, therefore, the distance between Alexandria and Syene to be a 50th part of a great circle upon the Earth, and having computed this distance to be 5000 stadia, he, from these data, determined the whole circumference of the Earth to be 250,000 stadia.

Posidonius, who was contemporary with Pompey the Great, endeavoured to measure the cir-

cumference of the Earth by observations upon Canopus, a bright star in the constellation Argo Navis. He was aware that this star, when on the meridian, was but just visible in the horizon of Rhodes, while its meridian altitude at Alexandria was 7° 30′, which is exactly one-48th part of 360°, or a great circle in the heavens. The distance between these two places he computed to be 5000 stadia, which, multiplied by 48, gives 240,000 stadia, which, as Cleomedes tells us, Posidonius found to be the circumference of the Earth. From this account of Cleomedes, Strabo, however, differs, and asserts the circumference of the Earth, as found by Posidonius, to be 180,000 stadia. The cause of this difference may be very easily explained: the distance between Rhodes and Alexandria had been measured by Eratosthenes, who found it to be but 3750 stadia; Strabo, therefore, making use of this measure and the number of degrees assigned by Posidonius, gives 180,000 stadia for the whole circumference of the Earth, according to the latter author.

Ptolemy, about the 144th year of the Christian æra, following Marinus, a celebrated geographer of Tyre, to whose writings he seems to have been under considerable obligations, makes use of this measure of 180,000 stadia in his geography, and asserts it to be more correct than that of Eratosthenès, which, notwithstanding, appears to have been more generally received before his time. Hence it is that this measure is, by Theon and others, ascribed to Ptolemy himself.

Our uncertainty relative to the precise value of the ancient stadium, prevents us from forming any correct opinion respecting the measures of these early mathematicians. I shall, therefore, proceed to speak of the more improved method by which

later astronomers have undertaken the solution of this important problem. This method consists in measuring the length of a degree of the terrestrial meridian. To perform this, two places are fixed upon nearly north and south from each other, and from that place at which the reckoning is to commence, the distance to some other convenient place is accurately measured in toises, fathoms, &c.; and this line is taken for the base of a triangle which becomes the first of a series of triangles, by means of which the distance between the two given places is to be measured. From each end of this base, the angle formed by some other place is taken, and these three points being now connected by lines, the first triangle is completed. The length of the base and the angle at each extremity of it being known, the length of the other two sides and the remaining angle are easily ascertained by trigonometry. One of the known sides of this triangle is made the base of a second triangle, the sides and angles of which are determined in a similar manner, and thus a series of triangles, all of which are connected at their base, is formed, and carried on to the other place chosen, and in this manner the direct distance between the two places is accurately ascertained, and by taking the azimuth of the sides at the points where this series of triangles begins and ends, the situation of one place with regard to the meridian of the other may be found. Snellius, professor of mathematics at Leyden, was the first who attempted this method of determining the circumference of the Earth, about the year 1617, by measuring the distance between Alcmaer and Bergen-op-zoom, and taking the elevation of the pole at these two stations. By this measurement he found the length of a degree to be 28,500 perches (each containing 12 Rhind-

land feet) or 19 Dutch miles; hence the whole periphery of the Earth is 6840 miles; a mile, according to him, containing 1500 perches, or 18,000 Rhindland feet.

Mr. Richard Norwood was the first among the English astronomers who endeavoured to ascertain the dimensions of the Earth, by measuring a degree of the meridian, and his efforts were more successful than those of any of his predecessors. His mode of estimating the length of a degree (the full particulars of which are given in his "Seaman's Practice,") was as follows: In the year 1635, he took the Sun's meridian altitude at London, on the day of the summer solstice, and repeated this observation at York on the same day of the following year, by which means he found the distance of latitude of these two places to be 2° 28′. He also measured with a chain the exact distance between London and York, making due allowances for the windings of the road, inequalities of surface, &c., and reduced this distance to an arc of the meridian, which he found to contain 12,849 chains, and by comparing this length with the difference of latitude between London and York, he found a degree contained 5209 chains, or about 57,424 toises, equal to 69½ English miles and 14 poles, whence he concluded the circumference of the Earth to be 25,036 miles, and its diameter 7966. This measure, in consequence of his inaccurate method of determining the distance between the two places, has been since proved to exceed the truth.

The importance of obtaining an accurate measure of a degree of the meridian induced the Royal Academy of Sciences at Paris, in the year 1669, to employ Picard for this purpose; and he appears to have been the first who brought the trigonome-

trical method of operation to any very great degree of perfection. By means of a series of triangles, the sides and angles of which were calculated by trigonometry, he found a degree of the meridian between Paris and Amiens to amount to 57,060 toises, or 69½ English miles, and consequently the circumference of the Earth to be 25,020 miles, and its diameter 7960.

This measure of Picard was afterwards continued to Dunkirk by La Hire, and from Paris to Perpignon by Cassini the younger, who having thus obtained the measure of an arc of the terrestrial meridian of several degrees, was enabled to calculate the length of each degree comprehended by that arc, and by a comparison of those degrees among themselves, he found, as he supposed, that the length of a degree increases as we approach the equator, and diminishes as we recede from it by almost an 800th part, and consequently that the Earth was a prolate spheroid, flattened at the equator, and swelled out at the poles. This inference, so diametrically opposite to that which had previously been deduced from the known laws of gravitation, naturally excited the attention of philosophers, and ultimately induced the French Academy of Sciences, sanctioned by Louis XV., to dispatch some of its members to the polar, and others to the equatorial regions, in order effectually to decide this question by measuring two degrees, so remote from each other that the probable errors in taking the angles should be of little or no importance compared with the inequality which it was expected would be found in the length of the degrees themselves. Accordingly, in 1735, two companies of mathematicians were sent out, the one on a northern, and the other on a southern expedition.

Messieurs Maupertuis, Clairaut, Camus, Monmer, and Outheir, who were sent to the north, reached Torneo in Sweden, at the northern extremity of the Gulph of Bothnia, and began their operations, assisted by M. Celsus, an eminent astronomer of Sweden, in July 1736, and after suffering severely from cold, and overcoming many obstacles, they succeeded by the end of May following, in measuring between Torneo and Kittis, that degree whose middle point is 66° 20′ north, and found it to contain 57,422 toises, being about 362 more than a degree in France.

Messieurs Godin, Bouguer, and Condamin, of France, who, together with Don Jorge Juan, and Don Antonio de Ulloa, of Spain, undertook the southern expedition, arrived safely in Peru, and began their operations in the province of Quito about October 1736; but owing to the almost insurmountable difficulties they had to contend with, and the extreme severity of the cold, from which, though so near the equator, they suffered much more than their associates in the polar regions, they did not finish them until the year 1741, when they succeeded, after many interruptions, in completing the measure of a degree near Quito, on the Andes, within about 13′ of the equator, and found it contained 56,750 toises, falling short of the length of a degree in France about 310 toises. By comparing the results of these operations, which were performed with every possible degree of accuracy, it obviously appears that a degree is longer near the poles than near the equator; and the following measurements of a degree in various parts of the Earth between these extremes, have tended to confirm the fact.

In 1740, Messieurs Cassini and La Caille, revising the former measures in France, found a

degree whose middle point is in latitude 49° 22′ north, contained 57,074 toises, and in the latitude of 45° north, it contained 57,057 toises. M. La Caille, in 1752, found the length of a degree near the Cape of Good Hope, in latitude 33° 18′ 30″ south, to be 57,037 toises. In 1755, Father Boscovich found the length of a degree between Rome and Rimini in Italy, in latitude 43° north, to be about 56,972 toises; and in 1766, a portion of the meridian in Maryland and Pennsylvania, North America, was measured by Messieurs Mason and Dixon, who give for the length of a degree, the middle point of which is 39° 12′ north, 56,904½ toises. A degree was also measured in India by Major Lambton, and another in England by Colonel Mudge, the former amounting to 56,755 toises, and the latter to 57,074.

From this statement, and from many other instances which might be quoted, it appears that the length of a degree gradually increases from the equator to the poles; the obvious inference to be drawn from which is, that the Earth is an oblate spheroid, having its greatest axis in the plane of the equator, an inference which we have already seen had been previously deduced by Newton, from the influence of gravity and the action of a centrifugal force.

Amidst such a variety of results relative to the actual magnitude of the Earth, it is not surprising that a great difference of opinion still prevails respecting it; taking, however, a mean of a great many measurements, the following dimensions may be considered as near the truth:

The circumference - - - -	25,000 miles.
The diameter - - - - - -	7,957¾ miles.
The superficies - -	198,944,206 miles.
The solidity - -	263,930,000,000 miles.

The circles parallel to the equator, commonly called the parallels of latitude, evidently decrease in magnitude as they approach the poles. Since, therefore, all circles are supposed to be divided into 360 equal parts called degrees, and since similar parts of different circles are in the same ratio to each other as the whole circles are, it follows, that the length of a degree in any parallel is as much less than the length of a degree on the equator as that parallel is less than the equator: thus, if the circumference of any parallel be equal to one-fourth of the circumference of the equator, a degree in that parallel will be only one-fourth part of the length of a degree on the equator, and so on.[1] Tables containing the length of a degree of longitude in every degree of latitude, are to be met with in most treatises on geography and astronomy.

From the difference observed in the length of the longest day in different parts of the Earth, the rising and setting of the Sun, and various other phenomena already explained, the ancient geographers divided the surface of this globe into certain tracts or portions, to which they gave the names of Climates[2], and instead of describing the

[1] The length of a degree in any parallel may be found by the following proportion, viz.: As radius is to the cosine of the latitude, so is the number of feet, yards, miles, &c. in a degree of the equator, to the number of feet, yards, miles, &c. in a degree of that parallel. This supposes the Earth to be a true sphere.

[2] From κλίμα, that which bends or inclines; because from the equator to the poles a gradual change takes place in the inclination or obliquity of the sphere. Some authors suppose that the climates were so called because they decline in order from the equator, and incline towards the poles; and others, that this name was given them on account of the difference in the length of the days being occasioned by the inclination of the Earth's axis to the plane of its orbit.

situation of any particular place by its latitude and longitude, their method was merely to state in what climate the place under consideration was situated.

A climate is a space upon the Earth's surface contained between two parallels, whose distance from each other is such, that the length of the longest day in one parallel exceeds that of the longest day in the other by half an hour. This method of dividing the surface of the Earth, though now comparatively but little used, is still adopted by some modern geographers, who, however, differ considerably from the ancients in the number of climates, and in the place from which they begin to reckon them. The ancients, whose scanty knowledge of geography led them to conclude that but a small portion of the Earth was inhabited, divided only those parts into climates with which they were acquainted, and in the room of beginning their reckoning at the equator, they commenced with that parallel in which the length of the longest day is twelve hours and three quarters, and thence counted their climates (which were originally only seven in number) northwards. Each climate was named from some remarkable place which was supposed to be situated in the middle of it, or rather upon a parallel which passed through the climate, in such a manner, that the longest day in that parallel differs a quarter of an hour from the longest day in either of the extreme parallels that bound the climate. It is obvious, therefore, that this parallel must divide the climate into two unequal parts, because the farther we go from the equator, the less increase of latitude will be required in order to increase the length of the longest day a quarter of an hour. The number of southern climates was soon after made to cor-

respond to that of the northern ones, and as no places were then known after which these climates could properly be named, each southern climate was called after its corresponding northern one. Thus the first of the northern climates being named Meroe, from a city in Africa, surrounded by the Nile; the first southern climate was denominated the climate against or opposite to Meroe, and so of the rest. As more of the inhabited parts of the Globe became known, the number of climates was increased, until at length the whole surface of the Earth from the equator to the poles became divided into climates, in the manner we now have them; for the modern geographers begin their climates at the equator, reckoning them by the increase of half an hour in the length of the day from the equator to the polar circles, where the longest day is twenty-four hours. From the polar circles towards the poles, some geographers count the climates by the increase of a natural day, in the length of time that the Sun continues above the horizon, till they come to a parallel within each of those circles where the longest day is equal in length to fifteen natural days, or half a month. From this parallel to the pole, they reckon by the increase of half months or whole months, the climates ending at the poles, where the days are six months long. The method, however, usually adopted in the present day is, to reckon six climates, increasing by months, from each polar circle to its respective pole, which, together with the twenty-four climates contained between each polar circle and the equator, make thirty climates in the northern, and as many in the southern hemisphere, and consequently sixty climates in all; of which those between the equator and polar cir-

cles are called hour-climates, and those between the polar circles and the pole, month-climates.

Another very ancient division of the Earth's surface proper to be mentioned in this place is into zones[1] or belts. These are five in number, viz. one torrid[2], two temperate, and two frigid[3] zones. The torrid zone is that portion of the Earth's surface which lies between the tropics, comprehending a space of about 47° of latitude, and is divided into two equal parts by the equator. The two temperate zones lie between the polar circles and the tropics, and contain each a space of about 43° of latitude. The frigid zones are those circumpolar regions comprehended by the polar circles. The torrid zone was thought by most of the ancients to be uninhabitable, by reason of the intense heat which they thought must prevail in those regions, to some part of which the Sun was constantly vertical; it is, however, now well known that many parts of it are inhabited, and that there is, perhaps, no part of it totally uninhabitable on this account, the heat of a vertical Sun being usually tempered by cooling breezes and refreshing showers. With respect to the frigid zones, none of the southern and only part of the northern is supposed to be inhabited.

To the inhabitants of the several zones, certain terms have been applied by the ancient geographers, arising from the difference in the length and positions of the shadows of terrestrial objects in those different parts of the Earth.

Those who live within the tropics, having the Sun sometimes to the north and sometimes to the south of them, are called Amphiscii[4], because by

[1] From ζώνη, a girdle. [2] From *torridus*, hot.
[3] From *frigidus*, cold.
[4] From ἀμφι, both; and σκία, a shadow.

this change in the relative position of the Sun a corresponding change is produced in the direction of their noon-day shadows, which must at some seasons of the year (namely, when the Sun is to the north of them) be projected towards the south; and at others (namely, when the Sun is to the south) be projected towards the north. Those who inhabit the temperate and frigid zones, that is, all those who live without the tropics, have their meridian shadows always directed the same way, and are called Heteroscii[1], because the inhabitants of the northern zones have their shadows at noon always pointing due north, while those who reside in the southern zones have theirs constantly directed to the south. Those Heteroscii, however, who live so far distant from the equator, that the days when at the longest are equal to or exceed in length a whole natural day, or twenty-four hours, are during that time called Periscii[2], because by the revolution of the Sun above their horizon (or rather by the rotation of the Earth on its axis) their shadows, in the course of twenty-four hours, are carried completely round them. When the Sun at noon is vertical to any place, the inhabitants of that place were by the ancients termed Ascii[3], that is, shadowless, because the shadow of a man or any upright object, when the Sun is in the zenith, falls directly on the place upon which the man or other object stands. Hence those who live under the tropics are sometimes called Ascii-Heteroscii, because when the Sun is in either of the tropics, upright bodies, situated on that parallel to which he is then vertical, project no shadow; but when the declination of the Sun decreases, a

1 From ἕτερος, another; and σκία.
2 From περὶ, about; and σκία.
3 From α, not; and σκία.

noon-day shadow is projected, but always in one direction. For a similar reason, the inhabitants of the torrid zone, or those who reside between the tropics, are sometimes denominated Ascii-Amphiscii, for the Sun will be twice in the year in the zenith of any place within that zone, and so there will be no shadow of upright objects, but at all other times a shadow will be projected, which will sometimes point to the north, and at others to the south.

Names have also been imposed upon the inhabitants of the different parts of the Earth, from their meridians, the parallels of latitude under which they live, and their situation with regard to one another. If two places were so situated, that on account of their proximity to each other there was no observable difference between their respective horizons, the inhabitants of those places were by the ancient geographers denominated Synœci.[1] These having the same horizon, must evidently have the seasons of the year and the length of the days and nights alike, and at the same time. The term Periœci[2] was applied to those persons who lived under the same parallel, but in distant parts of that parallel; these being on the same side of the equator, and at equal distances from it, have the seasons of the year and the length of days and nights the same, but the hours of the day differ in proportion to the distance of their meridians from each other. By most modern writers, those only are called Periœci who live in opposite points of the same parallel, and where, consequently, when it is noon to the one, it is midnight to the other. When two places lie under parallels equally distant from, but on con-

[1] From σὺν, with; and οἰκέω, to dwell.
[2] From περὶ, about: and οἰκέω.

trary sides of the equator, the inhabitants were called Antœci[1]. These have a similar increase of days and nights, and similar seasons, but in opposite months of the year. This appellation is, however, generally restrained by modern geographers to such as live under the same geographical meridian, and therefore have the day or night at the same time. If two places are in opposite hemispheres, but in parallels equally distant from the equator, and are also under opposite meridians, the inhabitants are called Antipodes.[4] Those who are Antipodes have a like elevation of the pole, but of different poles; they have also like days and nights, and similar seasons of the year, but they have opposite hours of the day and night, and their seasons happen in opposite months of the year. They have a common horizon, but the Sun, Moon, and Stars, rise to the one when they set to the other, and those stars which are in the circle of perpetual apparition of the one, are in the circle of perpetual occultation of the other.

In the survey we have now taken of the phenomena immediately connected with the Earth, no mention has been made of the tides, which being principally produced by the action of the Moon upon the waters of this terraqueous Globe, cannot be thoroughly understood without some previous knowledge of the lunar motions, and are, therefore, reserved for future discussion.

1 From ἀντὶ, against; and οἰκέω.
2 From ἀντὶ, and πόδες, the feet.

LECTURE XIV.

PHENOMENA OF THE SUPERIOR PLANETS AS SEEN FROM THE EARTH. — PHENOMENA OF THE SECONDARY PLANETS AS SEEN FROM THE EARTH. — OF THE MOON. — HER PHASES DESCRIBED. — OF THE LUNAR INEQUALITIES. — OF HER ROTATION ON HER AXIS. — OF HER LIBRATION. — OF THE HARVEST MOON. — OF THE HORIZONTAL MOON.

As the orbits of the superior planets comprehend the orbit of the Earth, these bodies may be seen in opposition to the Sun, and at all possible angular distances from him; they may also be in superior conjunction with that luminary, but they can never be in inferior conjunction, and consequently can never have their dark side wholly turned towards the Earth like the inferior planets, or like the Moon when new. They do not, however, always appear to move from west to east, according to the order of the signs, as they would be seen to do if viewed from the Sun, but like Mercury and Venus, they are sometimes direct, sometimes retrograde, and sometimes stationary.

The motion of a superior planet is direct, when, after being in conjunction with the Sun, it is seen to the west of that luminary, rising before him in the morning; its motion is also swiftest at this time, but as the apparent motion of the Sun is still more rapid than that of the planet, the latter will appear to recede from him, and continues so to do, the velocity of its motion gradually dimi-

nishing till, after a certain interval, it appears for a few days stationary; after which its motion becomes retrograde, and its velocity now gradually increasing while the Sun is moving in a contrary direction, the angular distance between these two bodies is rapidly augmented, and continues to increase, together with the retrograde motion of the planet, till the latter is in opposition to the Sun. After departing from the opposition, the planet is seen to the east of the Sun, setting after him in the evening, its retrograde motion still continues, and now tends to diminish the distance between the Sun and planet, the retrograde motion of which, however, now gradually becomes less and less, till at length it altogether vanishes, and the planet again becomes stationary. After remaining stationary for a few days, it resumes its direct motion, which has a tendency to increase the angular distance between it and the Sun; the latter, however, by the greater rapidity of his apparent motion, gains upon the planet, which, consequently, appears to approach the Sun, till it is a second time in conjunction with that luminary, after which it emerges from his beams and reappears in the morning as at the first.

These phenomena being common to all the superior planets, may be illustrated in the case of any one of them. I shall, therefore, make choice of Mars, the nearest of these bodies to the Earth, for this purpose, and, by means of a diagram, endeavour to give a clear elucidation of the whole of the foregoing particulars. As, however, those planets which are nearer to the Sun move faster in their respective orbits, and have, besides, much less space to pass through in going round that luminary than those which are more remote from him, it is obvious, that on both these accounts they must

complete their circuits sooner: we may, therefore, in order to simplify as much as possible this very intricate subject, suppose Mars to stand still in some particular point of his orbit, while the Earth performs one whole revolution about the Sun. Thus in diagram seven (which consists of two parts or pieces, numbered 1. and 2.)[1], let *a b c d e f g h i k*, No. 1., represent the orbit of the Earth; A B C D, the orbit of Mars, *m* Mars, and C the point of his orbit in which he is supposed to continue while the Earth goes once round the Sun in the order of the letters *a b c d*, &c.; also, let S, No. 2., of the same diagram, be the Sun, and E the Earth. The line *v l* proceeding from the Earth and passing through the centre of the Sun, is the visual line, in which the Sun appears to a spectator on the Earth's surface, and the silk string is the visual line of Mars. This line is to be kept constantly stretched over the centre of that planet, and extended to the ecliptic, while the Earth is made to revolve round the Sun.

Now, when the Earth is at *a*, Mars, supposed stationary at C, will be in the same right line with the Earth and Sun, as is shown by the coincidence of the two visual lines, and will consequently be in

[1] In future, when any diagram is mentioned, it will be taken for granted, that before reading the description of it, the several parts of which it is composed are ranged on the machine in their regular order, always beginning with No. 1, of every diagram, and placing them so that the letters of reference of chief importance on each part may stand in their natural position at the commencement of the illustration, unless any particular direction be given to the contrary: thus, when the letters C A on part 1. of the above diagram are due nor[illegible]d south, all the letters of reference upon that part ar[illegible]r natural position; part 2. being then put on, and the[illegible]E S (the principal letters on that part), being also pl[illegible]heir natural position, the whole diagram is prepar[illegible]use.

conjunction with that luminary in the beginning of Cancer, that being the point of the ecliptic to which both the Sun and Mars will be referred by the eye of a spectator on the Earth. While the Earth is moving from *a* to *b* in its orbit, Mars, whose apparent motion is now direct, will appear to move through about five degrees of Cancer, but will seem to recede from the Sun, whose more rapid apparent motion will carry him in the same time to the 28th degree of the same sign. While the Earth is going from *b* to *c*, Mars will appear to advance about four more degrees in the ecliptic, its motion still continuing direct, but decreasing in velocity; and when the Earth is at C, the Sun, whose angular distance from Mars has rapidly increased, will be just entering the sign Virgo. While the Earth is moving from *c* to *d* and from *d* to *e*, the direct apparent motion of Mars continues, and when the Earth arrives at *e*, the Sun appears in about the 10th degree of Scorpio, and Mars in about the 16th of Cancer. Mars will now appear stationary for a short time, the visual line being a tangent to the Earth's orbit, after which, its apparent motion will become retrograde, and while the Earth moves from *e* to *f*, Mars will appear to return back again to C, its retrograde motion becoming more rapid as it approaches C, where Mars is in opposition to the Sun and its motion a maximum. While the Earth is moving from *f* to *g*, the retrograde motion of Mars continues, but its velocity gradually diminishes, and as the apparent motion of the Sun is always direct, the retrograde motion of Mars now tends to diminish the angular distance between them. When the Earth is at *g*, the visual line of Mars is again a tangent to the Earth's orbit, and Mars once more appears stationary in the heavens, its apparent place in the

ecliptic being about 14° of Gemini, and its angular distance from the Sun the same as it was when the Earth was at *e*. After remaining stationary for a short time, the apparent motion of Mars again becomes direct, and he is therefore retreating from the Sun; the velocity of the latter, however, is so much greater than that of Mars, that their angular distance nevertheless diminishes while the Earth is moving through the arc *g h i k a*, and when the Earth arrives at *a*, Mars is again in conjunction with the Sun as at the first. The angular distances between the Sun and Mars are not quite correctly shown in this illustration, the cause of which is obvious from what was said with respect to the angular distances between the Sun and the inferior planets, Mercury and Venus, when the apparent motions of those bodies were treated of.

Mars has hitherto been considered stationary in one particular point of its orbit, while the Earth was moving round the Sun; this is not, however, the case, Mars and all the other superior planets really revolving round the Sun in the same direction as the Earth, but moving much slower in their respective orbits; the same phenomena, however, take place, but happen at different times, and when the Earth is in different parts of its orbit.

The phenomena we have now been describing are common to all the superior planets, but happen under somewhat different circumstances on account of the slower motion of those which are more distant from the Sun. The nearer a superior planet is to the Sun the greater will be the time employed by it in passing from conjunction to conjunction again; the greater the angular distance at which it becomes stationary, and the greater the arc of retrogradation, but the less will be the time in which the retrogradation is performed.

While a superior planet is advancing towards its conjunction with the Sun, the velocity of its apparent motion gradually increases, and as gradually diminishes from conjunction to the point at which it becomes stationary; in retrograding from this point its velocity again increases till the planet is in opposition, at which instant the rapidity of its motion begins once more to decrease, and continues so to do till the planet becomes a second time stationary, after which it is again seen to approach its conjunction with an increasing motion, and the foregoing phenomena are again repeated in the same order.

The apparent diameter of a superior planet is variable, being greatest when that planet is in opposition to the Sun, and least when it is in conjunction with him. In the intermediate points of its orbit, its apparent diameter varies between these two extremes, being greater or less according to the proximity of the planet to the one or the other of these situations.

The orbits of the superior, like those of the inferior planets, being inclined to the plane of the ecliptic, their latitude or distance from the ecliptic must be perpetually varying, and instead of appearing to move continually backward and forward in a straight line, as they would do if the planes of their orbits coincided with the plane of the ecliptic, they will seem to describe a succession of irregular looped curves among the fixed stars. This will be understood from fig. 29,[1] representing the apparent path of Jupiter, from the beginning of 1708 to the beginning of 1710. In this figure, E C

[1] This figure was originally given by Dr. Robison in the Elements of Mechanical Philosophy. A similar figure is to be met with in the Edinburgh Encyclopœdia, plate xl. fig. 5.

represents the ecliptic, and the two first letters of every month are put to the places in Jupiter's path where he was on the first day of that month. Each of the loops at L, L, is formed every thirteenth month, the planet being in opposition to the Sun when he is in the centre L of each loop.

The apparent path of any other planet or of Jupiter for any other time may be easily drawn by taking the geocentric latitudes and longitudes at the commencement of every month from the Nautical Almanac, and laying them down in a similar manner. The orbits of the superior planets being much larger than that of our Earth, the greater portion of their enlightened side is constantly turned towards us, generally appearing almost like the Moon when full.

Having taken a comprehensive survey of the motions and general appearances of the primary planets, we may proceed in the next place to contemplate the

PHENOMENA

OF THE

Secondary Planets, Satellites, or Moons.

It has been already remarked, that besides the Earth, 'which is accompanied in its revolution round the Sun by the Moon; Jupiter, Saturn, and Uranus, are likewise attended by satellites, of which Jupiter has four, Saturn seven, and Uranus six. In describing the motions, &c. of these bodies, we shall, of course, commence with

The Moon,

whose various appearances (commonly called her phases) during her progress round the heavens,

cannot fail to have attracted universal attention, and they, in fact, constitute some of the most striking of the celestial phenomena. When the Moon, after having been in conjunction with the Sun, emerges from its rays, in the evening she appears after Sun-set like a fine luminous crescent, having its convex side turned towards the Sun. As she recedes from that luminary, this crescent gradually increases in breadth, and when she has gone through an eighth part of her revolution, she is said to be in her first octant, at which time one-fourth part of her enlightened side is turned towards the Earth. As her distance from the Sun increases, she presents more of her enlightened side to our view, and when she has completed a fourth part of her revolution, she appears a half-moon or dichotomised [1], and is said to be a quarter old. In rather less than four days more she is in her second octant, when she becomes gibbous [2], exhibiting an intermediate figure between a half and a full Moon. Her distance from the Sun continues to increase, until at length she is in opposition to that luminary, when her enlightened hemisphere is wholly turned towards the Earth, and she shines with a full illumined orb, at which time she comes to the meridian at midnight. The enlightened portion of her disc now begins to diminish, and when she arrives at her third octant, she again becomes gibbous. Her enlightened side continues to be withdrawn more and more from the Earth, and when she arrives at her third quarter, only one half of it is visible. She still continues to approach the Sun, and having reached her fourth octant, she once more appears horned, having

[1] From διχότομος, cut into two parts.
[2] From *gibbus*, crooked or bunched out.

only a quarter of her enlightened hemisphere turned towards the Earth; at this time she is seen in the east, rising a little before the Sun, till at length, having completed her revolution, she is again in conjunction with that luminary, and disappears, her dark side being turned towards the Earth. The Moon, in this situation, is said to be new.

These changes in the appearance of the Moon are repeated in the same order every lunation, the Moon constantly exhibiting the same phase at the same angular distance from the Sun, from which we naturally infer that the Moon is an opaque globular body, deriving her light from the Sun, her changes or phases being produced by her situation relatively to the Earth and that luminary. This will be better understood from diagram 8., in which, let S be the Sun, E the Earth, and M the Moon. When the Moon is at *a* in conjunction with the Sun, her dark hemisphere being turned directly towards the Earth, she becomes invisible as at A. When the Moon has advanced from *a* to *b*, having gone through an eighth part of her orbit, she is said to be in her first octant; a small portion of her enlightened hemisphere is now turned towards the Earth, and she appears as at B. In this situation the Moon is said to be horned. When she reaches *c*, she is in her first quarter and appears as at C, one half of her enlightened side being turned towards the Earth. As she continues to move forward in her orbit, more and more of her enlightened hemisphere becomes visible, and at *d*, being in her second octant, she appears gibbous as at D. At *e* she is in opposition to the Sun, her whole illuminated hemisphere is now turned towards the Earth, and she appears full as at E. From this point of her orbit she begins

gradually to present less and less of her illuminated disc to the Earth, and when she reaches her third octant at *f*, she again appears gibbous as at F. At *g* she is in her third quarter, and again presents half her enlightened hemisphere to our view as at G. In her fourth octant, she once more assumes the form of a crescent as at H; and at *a* she again becomes invisible, being once more in conjunction with the Sun.

Those points of the lunar orbit in which she is new and full, or in conjunction and opposition, are called the syzigies,[1] and those points in which she is 90° from the Sun, the quadratures.

It will be seen by inspecting the diagram, that the Earth exhibits the same phases to the inhabitants of the Moon (if such there be) as the Moon presents to a spectator on our globe, but in an inverted order, the Earth being new, and consequently invisible to them when the Moon is full to us: they must have a waxing when we have a waning Moon, and thus all their lunar seasons must be exactly the reverse of ours. It is only from one side of the Moon (as will hereafter be shown) that the Earth can ever be seen; but to those who live on that side, it must, on account of its vast magnitude compared with that of the Moon, present a much more magnificent spectacle than she does to us.

The revolution of the Moon from one conjunction with the Sun to the next, during which her various phases are exhibited in the manner already detailed, is called a synodical revolution, the mean period of which is 29 days 12 hours 44 minutes 2·8 seconds. This period is also called a lunation.

[1] From συζυγια, union.

The sidereal revolution of the Moon is performed in 27 days, 7 hours, 43 minutes, 11·5 seconds, being the time she employs in moving from any fixed star to the same fixed star again. The sidereal or true revolution of the Moon is less than the synodical, the greater length of the latter being caused by the motion of the Earth in its orbit, whereby the Sun appears to advance rather more than 29° in the ecliptic, while the Moon goes once round the Earth; the difference, therefore, between these two revolutions is equal to the time occupied by the Moon in passing over this space, so as again to come into conjunction with the Sun.

The periodical or tropical revolution is the time which the Moon takes to revolve from one equinox to the same equinox again; this is less than the sidereal revolution, for the equinoxes, during the latter period, recede about four seconds of a degree, a space which the Moon passes over in rather less than seven seconds of time, hence her periodical revolution is performed in 27 days, 7 hours, [illegible] minutes, 4·7 seconds.

While the Moon revolves round the Earth, the Earth is itself in constant motion round the Sun, the path of the Moon, therefore, in absolute space, is very different from that which she appears to describe about the Earth, being, in fact, a series of epicycloidal curves, always concave towards the Sun.

The figure of the orbit in which the Moon circulates about our Globe is nearly that of an ellipse, and would be truly so if the distance of the Sun from the Earth in respect of that of the Moon were infinite, in which case, as they would both be equally attracted in parallel straight lines, and at all times uniformly, so their relative motion would not be in the least disturbed. The distance, however, of the Moon from the Earth, though much

less than that of the Sun, bears, notwithstanding, a very sensible proportion to it, and consequently the angular distance between the Earth and Moon is perpetually varying; the Sun, therefore, acts unequally and in different directions upon these bodies, thereby producing those changes in the form of the lunar orbit, and causing those deviations from the true elliptical motion, which are denominated the lunar inequalities. Of these phenomena, which may be classed among the most interesting and useful, but at the same time, the most intricate subjects of astronomical investigation, I shall endeavour to give as comprehensive a view as the compendious plan of these lectures will possibly admit, and in so doing, I shall first of all consider the orbit of the Moon a perfect circle, as A B C D, fig. 30. In the same figure, let E be the Earth, *m* the Moon, and S the Sun.

When the Moon is in the last quarter at A, her distance from the Sun S will be nearly the same as that of the Earth. As, therefore, the Earth in going round the Sun is constantly descending towards it, so the Moon, if she continued in the same point of her orbit while she accompanied the Earth in its progress round the Sun, must, in any equal portion of time, descend as much, the relative situation of the Earth and Moon being in no respect altered, and, consequently, the Sun's action upon both continuing the same. But as the Moon advances from the quarter towards the conjunction, suppose to *b*, her distance from the Sun diminishes, and, consequently, the action of the latter upon the Moon increases, while, in respect of the Earth, it still remains the same, and, consequently, an acceleration is produced in the motion of the Moon, which acceleration is not caused simply by the Sun's attraction of the Earth

or Moon, but by the Moon at *b* receiving a greater impulse from the Sun than the Earth at E, in consequence of her beingnearer to him; for if the Sun's action upon the Moon were equal to its action on the Earth, and exerted in the direction *b c* parallel to E S, no disturbance would take place in the apparent motion of the Moon round the Earth. But the Moon at *b* being more powerfully attracted than the Earth at E, its motion through the arc *b* B would be accelerated, were the Sun to act in the direction *b c* parallel to E S; this acceleration, therefore, is still farther increased by the oblique direction of the Sun's attraction. The Moon's motion, therefore, from the last quarter to the conjunction being continually accelerated, its velocity increases till it arrives at B. From the conjunction B to the next quarter C, the distance of the Moon from the Sun increases, and, consequently, its motion is gradually retarded till it arrives at C, where, being again in quadrature, its distance from the Sun is again nearly the same as that of the Earth. In going from C to D, or from the first quarter to the opposition, the Moon is receding from the Sun, the Earth is now, therefore, nearest to him, and, consequently, more attracted by him than the Moon; whose motion, for this reason, appears to be accelerated, the same effect being now produced by the deficiency of the Sun's action on the Moon, from what it has on the Earth, as was produced by the excess of it while the Moon was going from A to B. In moving from the full or opposition to the third quarter, the excess of the Sun's attraction upon the Earth again diminishes, and the Moon's velocity is constantly retarded, and when she arrives at A, the Sun's action upon the two bodies is again nearly equal. From what has now been said, it appears that the velocity of the Moon's motion is greatest in the

syzigies, and least in the quadratures. About the octants its velocity is nearly in a mean state. In the first and third octants, the Moon is about 37 minutes to the eastward of her mean place, and in the second and fourth, it is as much to the westward. This alternate acceleration and retardation of the Moon in her orbit was first observed by Tycho Brahe, who called it her variation.

When the Moon is in conjunction, she is nearer the Sun than the Earth is; the Sun, therefore, attracting her more forcibly than it does the Earth, her tendency towards the latter is diminished, and her orbit becomes less incurvated; for the inflection from a rectilinear course, being the effect of her tendency towards the Earth, the more that tendency is diminished, the less will be the inflection produced. Precisely the same effect takes place at the opposition, for the Moon being then more remote from the Sun than the Earth is, the effect of the Sun's attraction upon the latter is greater than upon the former, and, consequently, the Moon's tendency to the Earth is again diminished, and its orbit, in respect to the Earth, approaches nearer to a straight line. But when the Moon is in quadrature, her distance from the Sun being nearly equal to that of the Earth, they both descend with equal velocity towards the Sun, and, therefore, her gravitation to the Earth is increased. This increase in the tendency of the Moon towards the Earth by the solar action in the quadratures, is equal to about one-half the quantity, by which the same tendency is diminished in the syzigies. It follows, therefore, that were the orbit which the Moon would describe about the Earth, if undisturbed by the Sun's attraction, a circle, the effect of this disturbing force would be to change it into an oval, approaching very near to an ellipse,

having the Earth in its centre, and its longer axis nearly coincident with the line of the quadratures. Sir Isaac Newton computed the distance of the Moon from the Earth in quadrature, to be to its distance in syzigy, as 70 to 69.

The lunar orbit, however, although not very eccentric, is, in fact, an ellipse, one of the foci of which is occupied by the Earth. When, therefore, the line of the apsides coincides with the line of the syzigies, the eccentricity of the orbit is increased; and it is decreased when the line of the apsides coincides with that of the quadratures. These changes in the eccentricity of the Moon's orbit sensibly affect the equation of the centre.

Another effect produced by the disturbing force is the motion of the apsides. When the Moon is in syzigies, the line of the apsides has a direct motion, and a retrograde motion when she is in her quadratures; but, during the course of one complete revolution of the Moon about the Earth, the progress exceeds the regress. The apsides will advance most and recede least when the line of the apsides coincides with the line of the syzigies. The contrary happens when the line of the apsides lies near the line of the quadratures, in which case the regress exceeds the progress. In the octants the apsides advance with a mean motion, but by reason of the accumulation of the variations, the difference between their mean and true places is then at a maximum. The apsides, in the course of an entire revolution of the Earth about the Sun, have every possible position with respect to the line of the syzigies, and, upon the whole, the natural gravitation of the Moon being more diminished than increased, they advance, their mean motion being about three degrees in a revolution.

The Moon's orbit has hitherto been considered coincident with the plane of the ecliptic; this is

not, however, the case, her orbit being in reality inclined to it, and making with it an angle of about five degrees. One of the effects resulting from the action of the solar force, is to produce a change in the position of the line of the nodes. When the line of the nodes coincides with the line of the syzigies, the nodes are at rest. When the Moon is between the node and the nearest quadrature, the nodes advance a little forward, but retreat while she proceeds from a quadrature to the next node. In each synodical revolution of the Moon, however, the nodes retreat more than they advance, the result, therefore, of these movements, is a complete revolution of the nodes from any point of the ecliptic to the same point again, in a period of 18 years, 228 days, 7 hours, 13 minutes, 17·7 seconds, at the rate of 19 degrees, 19 minutes, 43 seconds, annually.

By the same force, which produces the foregoing changes in the position of the nodes, the inclination of the Moon's orbit to the plane of the ecliptic is also affected. When the line of the nodes passes through the syzigies, the plane of the Moon's orbit produced, passes through the centre of the Sun, and consequently, not being affected by the Sun's attraction, its inclination is the greatest possible, being then about 5 degrees, 18½ minutes. From this time till the line of the nodes is in quadrature with the Sun, the Sun's action upon the Moon tends to bring her nearer to the ecliptic, and thereby to lessen the angle formed by the plane of the Moon's orbit with the plane of the ecliptic, and when the line of the nodes is in quadrature, this angle is the least possible, and it again gradually increases till the line of the nodes reaches the line of the syzigies.

The distance of the Earth itself from the Sun is not constantly the same, but varies in the course of a year, on account of the elliptical form of its orbit; it therefore follows, that the lunar inequalities must be very considerably affected by this circumstance; the Sun's attraction, by which these inequalities are produced, being greatest when the Earth is in its perihelion, and least when it is in aphelion. It has already been shown that in the quadratures the gravitation of the Moon to the Earth is increased, and that in the syzigies it is diminished; it has also been observed, that the diminution which takes place at the syzigies is about double the quantity, by which the gravitation is increased in the quadratures, the consequence resulting from which is, that the Moon revolves about the Earth at a greater distance and in a longer time than if her motion was undisturbed by the Sun's attraction. The greater, therefore, the disturbing force is, the greater will be the diminution of the Moon's gravity, and the longer the time in which her revolution is performed. As, therefore, the Sun is nearest to the Earth in winter, the periodical month is a little longer at that season than in summer, when the Earth being farther from the Sun, his disturbing force is less powerful. This inequality of the Moon's motion, arising from the change in the magnitude of her orbit, and her periodic time, according to the place of the Earth in the ecliptic, is called her annual equation.

In addition to the inequalities already mentioned, to which the lunar motions are subject, another small irregularity has been taken notice of by astronomers, called the secular equation. This arises from a continual acceleration of the Moon's motion, caused by the action of the Sun upon the Moon, combined with the variation of the eccentricity of the

Earth's orbit. This inequality was first observed by Dr. Halley, but for the discovery of its cause we are indebted to La Place. In consequence of the action of the planets upon the Earth, the eccentricity of its orbit is at present decreasing, although the greater axis of the orbit is not in the smallest degree affected by their action; since, therefore, the mean force of the Sun to expand or contract the Moon's orbit, depends upon the square of the eccentricity of the Earth's orbit, by the diminution of this eccentricity at present taking place, the Moon's mean motion is accelerated. When, therefore, the eccentricity becomes a minimum, this acceleration will cease, and when the eccentricity increases, the mean motion of the Moon will be retarded. The diminution, according to La Place, is 11·135 seconds in a century, and this change of angular velocity produces a change in the longitude of the Moon, which, like any other uniformly accelerated motion, is in the duplicate ratio of the time. Hence the correction for the Moon's longitude, calculated by the present tables, is found by multiplying the square of the number of centuries backward or forward by 11·135 seconds.

Having thus briefly described the principal of those inequalities which affect the Moon's motion, and which, by embarrassing the lunar theory with almost insuperable difficulties, render the calculation of its true place in the heavens one of the most laborious and intricate problems in the science of astronomy; I shall proceed to speak of its rotation on its axis, the only equable motion of this satellite.

The Moon turns exactly once round on its axis while it performs a synodical revolution in its orbit, as is evident from her always presenting the same

side to the Earth, for if she had no rotation upon an axis, every part of her surface would be presented to a spectator upon the Earth in the course of her monthly revolution. That side of the Moon, therefore, which is next the Earth, is never involved in total darkness, the Earth affording it a powerful light during the absence of the Sun, it therefore enjoys successively two weeks of illumination from the Sun, and two weeks of moonlight from the Earth. The other side has a fortnight's light and a fortnight's darkness by turns. The lunar day and night is therefore a month long, and her axis being nearly perpendicular to the plane of the ecliptic (the angle it makes with that plane being 88° 29′ 49″), there is scarcely any diversity of seasons in the Moon. But although the Sun never declines materially from her equator, and consequently, the lunarians enjoying a perpetual equinox, cannot determine the length of their year in the same manner that we can the length of ours, yet, they may, by observations upon the polar regions of our Earth, ascertain it with great ease; and it has been supposed that this is the method which would most probably be resorted to by them for resolving this problem; for as the north pole of our Earth begins to be enlightened at the time of the spring, and the south pole at the time of the autumnal equinox, it is evident, that by observing when either of our poles begins to be enlightened, and the other to disappear, they may ascertain the length of their year; which is, in fact, the same as that of ours, although the number of natural days contained in it is very different, ours consisting of 365¼, theirs of little more than 12.

Although the motion of the Moon about her axis is perfectly equable, yet, the disc of the Moon

presented to our observation, is subject to certain small variations, by which the spots on the eastern limb are sometimes withdrawn, and vanish behind that limb, while others appear on her western limb which were not before visible. Again, the last mentioned spots become invisible, disappearing behind the Moon's western margin, while those which had withdrawn themselves behind her eastern margin, reappear in their original situations. The northern and southern limbs of the Moon are also found to undergo similar changes. These phenomena are comprehended under the general name of the Moon's libration, which is of four kinds, viz.: the libration in longitude, the libration in latitude, the diurnal libration, and the spheroidal libration.—Of these different species of libration, the three first are merely apparent, and consequently do not affect the real motion of the Moon about her axis; the fourth arises from the action of the Earth on the lunar spheroid, producing a trifling inequality in her rotation. The two first of these apparent irregularities were originally noticed by Galileo, the third was discovered by Hevelius, and the spheroidal libration was first remarked by La Grange.

The libration in longitude arises from the uniformity of the Moon's motion about her axis, combined with her unequal motion in her orbit. Were the orbit in which the Moon revolves round the Earth a perfect circle, having the Earth in its centre, and were the Moon's motion therein uniform, her rotation on her axis being performed in the same time as her revolution in her orbit, there would be no libration in longitude, because the Earth would be constantly vertical to the same lunar meridian, and the same face of the Moon would be constantly and exactly turned towards

the Earth. But since the Moon moves unequally in an elliptic orbit round the Earth, placed in one of the foci while she revolves equably on her axis, the plane of no one lunar meridian will constantly pass through the centre of the Earth, and consequently she will not, in every point of her orbit, have precisely the same face presented to us. The libration, in longitude, at its maximum, which happens when the Crisian Sea is about ¾ of its width, from the western limb of the Moon, is about 7° 30′, and it altogether vanishes in perigee and apogee.

The libration in latitude arises from the declination of the Moon's axis, from a perpendicular to the plane of the ecliptic, whereby the lunar axis, which always preserves its parallelism, sometimes inclines towards the Earth, and at other times declines from it, thus bringing the north pole and the parts adjacent into view, during one half of her revolution round the Earth, and the south pole and south polar regions, during the other half, one pole of the Moon constantly withdrawing itself from our observation, as the other becomes visible.

The diurnal libration arises from the somewhat different views a spectator on the Earth's surface obtains of the Moon at the time of her rising, culminating and setting, and is therefore dependant on the motion of the observer about the centre of the Earth; for it is easy to conceive, and observation proves, that at the time of the Moon's rising, certain spots are visible about the upper limb, which disappear as she advances to the meridian, while others about the opposite limb of the Moon, not before observable, come into view as she approaches towards and descends below the western verge of the horizon.

The fourth kind of libration is caused by the action of the Earth on the elevated parts of the lunar spheroid, whereby a small vibratory motion of the Moon is produced about an axis, perpendicular to the radius vector, or line joining the Earth and Moon.

The mean motion of the Moon from west to east in her orbit, is at the rate of about 12° 11′ in a day, she is, therefore, generally supposed to rise about 50′ later every day than on the day preceding; this is, however, only true in regard to places situated on the equator. In places of considerable latitude, there is a remarkable deviation from this period of daily retardation in the rising of the Moon, and this difference is most conspicuous in the autumnal season, when the full Moon appears to rise for several successive evenings about the time of sunset, or so long before the termination of twilight, as to enable the husbandman to continue his labours to a late hour without interruption, and is thence called the harvest Moon.

The equator making always equal angles with the horizon, if the Moon's orbit coincided with the plane of that circle, her time of rising would vary daily about 50 minutes. The Moon's orbit, however, is nearly coincident with the plane of the ecliptic, and consequently, different parts of it make different angles with the horizon as they rise or set, those parts which rise with the smallest angles, setting with the greatest, and *vice versa*. Now, the less this angle is, the greater portion of the orbit rises in the same time. When, therefore, the Moon is in those parts of her orbit which rise or set with the smallest angles, she rises or sets with the least difference of time, and when she is in those parts of her orbit which rise or set with the greatest angles, she rises or sets with the

greatest difference of time. 'But in northern latitudes, the smallest angle of the ecliptic and horizon is made when Aries rises and Libra sets, and the greatest, when Libra rises and Aries sets; when, therefore, the Moon rises in Aries, she rises with the least difference of time. Now, the Moon is obviously in opposition, in or near Aries, when the Sun is in or near Libra, which happens in the autumnal months, and it will be seen by making the experiment with a common globe, that when the Moon is in the twenty-third degree of Leo, where the ecliptic makes the greatest angle with the horizon, an hour and a quarter must elapse before 12° 11' of the ecliptic will ascend above the horizon, and consequently, the Moon will at that time rise one hour and a quarter later on the following evening, whereas, if the Moon be in the beginning of Aries, where the ecliptic makes the least angle with the horizon, the same portion of the ecliptic will appear above that circle in about a quarter of an hour, so that the moon seems to rise for several successive nights nearly at the same time.

The same phenomenon takes place every lunation, but as the Moon is not full when it happens, except in the harvest months, the circumstance passes unnoticed. Since the Moon is always in opposition when full, and since the harvest Moon can never happen, but when she is in Pisces and Aries, and consequently, when the Sun is in the opposite signs Virgo and Libra, it is obvious there can be no more than two full Moons in a year, which rise nearly at the setting of the Sun for almost a week together. The first of these Moons is known by the name of the harvest, and the second by that of the hunter's Moon.

The Moon has hitherto been considered, while describing the phenomenon of the harvest Moon, as moving in the plane of the ecliptic, her orbit, however, is not coincident with that plane, but inclined to it at an angle of about five degrees and a half, it therefore intersects the ecliptic in two opposite points, called (as we have before observed) her nodes; one-half, therefore, of her orbit is above, and the other half below the ecliptic. In order to understand the full effect of the harvest Moon, it will be necessary to observe, that the part of the lunar orbit at the ascending node, where the Moon rises above the ecliptic, must make a more acute angle with the horizon than the ecliptic itself, and, on the contrary, that the part of the lunar orbit at the descending node, where she descends below the ecliptic, must make a greater angle with the horizon than the ecliptic itself. When, therefore, the ascending node is in Aries, the northern half of the Moon's orbit will extend beyond the ecliptic, and as her orbit then makes an angle of 5½ degrees less with the horizon than the ecliptic, the beneficial effects of the harvest Moon will be increased. On the contrary, when the Moon's descending node is in Aries, the northern half of the Moon's orbit will be below the ecliptic; and as her orbit in the latter instance makes an angle with the horizon, 5½ degrees greater than when she is in the ecliptic, the beneficial effects of the harvest Moon will be diminished. Now, the Moon's nodes perform a complete revolution round the ecliptic in about 18 years, 225 days, consequently, if the Moon's ascending node is in the beginning of Aries at any given time, the descending node will occupy the same place after an interval of about 9 years, 112

days. There will, therefore, be an interval of about 9⅓ years, between the most beneficial and the least beneficial harvest Moons.

These phenomena are as regular in the southern as in the northern hemisphere, but take place at contrary times; the harvest Moon in south latitude being the full Moon that happens at or near the vernal equinox.

The Moon when near the horizon appears much larger than when in the zenith, although, in the latter situation, it is about 4000 miles, or the semidiameter of the Earth nearer to us than in the former, and consequently ought to appear larger, and it is accordingly found by actual measurement, to subtend a larger angle, when in the zenith or on the meridian, than it does when near the horizon. This will be understood from fig. 31., in which E represents the Earth, A the place of an observer, M the moon in the zenith, and *m* the Moon in the horizon. A mere glance at the figure is sufficient to show that the distance of the Moon at *m*, from the spectator at A, is much greater than when it is at M, and that the angle under which it appears at M is greater than at *m*.

In order, therefore, to account for the increase in the apparent magnitude of the horizontal Moon, some authors assert that the pupil being more expanded in consequence of the diminished brilliancy of the Moon when near the horizon, a larger image is formed upon the retina. It seems, however, more probable, that the increase of apparent magnitude in the horizontal Moon, is nothing more than an optical illusion, and may be explained upon the same principle, by which we always endeavour, in forming a judgment of the magnitude of very remote objects, to compare them

with some intervening object whose size is known. Thus, in viewing the Moon in the horizon, we involuntarily compare her with terrestrial objects, with whose general magnitude we are acquainted, while the Moon in the zenith is seen, as it were isolated in the widely extended hemispherical vault, and consequently appears considerably smaller.

LECTURE XV.

PHENOMENA OF THE SECONDARY PLANETS AS SEEN FROM THE EARTH CONTINUED. — OF SOLAR AND LUNAR ECLIPSES.

THE phases and motions of the Moon having been explained at considerable length in my last lecture, I shall, in the next place, proceed to give a general view of the nature and causes of solar and lunar eclipses, the transition from an explanation of the lunar motions to that of the doctrine of eclipses being both easy and natural. It is easy, because a thorough understanding of the former will greatly facilitate the comprehension of the latter; and it is natural, because eclipses, though generally considered as of two kinds, namely, solar and lunar, may be more properly comprehended under the head of lunar than solar phenomena, since a lunar eclipse (as will hereafter be shown) is properly so called, being a deprivation of light which the Moon undergoes in consequence of the interposition of the Earth between her and the Sun, the only luminous body in the system, while an eclipse of the Sun, as it is commonly denominated, is in reality no eclipse of that luminary, whose brilliancy always remains unimpaired, but is, in fact, only a partial eclipse of the Earth, caused by the Moon coming between the Earth and Sun, whereby certain portions of the Earth's surface are deprived of the light of the Sun during the continuance of the phenomenon.

No celestial phenomena with which we are acquainted have perhaps more particularly engaged the attention of mankind than the eclipses of the Sun and Moon. In the remote ages of antiquity the obscurations of these bodies were looked upon with terror and amazement, and generally regarded by the vulgar in all ages as portentous omens presaging some dreadful calamities about to take place. An eclipse of the Sun, especially if it happened to be total, was supposed by the ancients to be caused by his turning away his face in detestation of some horrible crime, either already committed or about to be perpetrated upon Earth; and the Moon, when eclipsed, was considered as enduring violent pains, on which account eclipses were frequently denominated *lunæ labores*.

In a chronological point of view, eclipses are of considerable importance, since they afford the most certain method of determining with accuracy the dates of many past occurrences recorded in ancient and profane history. Geography has also been much benefited by these phenomena, which are frequently employed in determining the longitude of places on the Earth's surface, and afford besides a convincing proof of the Earth's rotundity.

The shadows of the Earth and Moon being so materially concerned in the production of eclipses, it may be proper, before entering upon a description of the phenomena themselves, to make a few brief observations relative to the figure of shadows cast by opaque spherical bodies in general.

Every opaque body enlightened by a luminous one, must cast a shadow in a direction opposite to that of the illuminating body, and parallel to the rays of light by which it is illuminated, and the strength of the shadow will be in proportion to the intensity of the light received; not indeed that the

shadow is of itself darker, for all perfectly opaque bodies entirely intercept the rays of light, whatever may be the degree of intensity with which that light falls upon them, and consequently cast, at all times, the same degree of shade; but the shadow will obviously seem stronger as the contrast is greater, and consequently, the more intense the light, the stronger will the shadow appear.

If the luminous body be smaller than the opaque one, the shadow will continually increase in breadth the farther it recedes from the latter, assuming the figure of a truncated cone, with the apex towards the opaque body. This figure of the shadow is sometimes called calathoeides.[1]

If the luminous body be equal in magnitude to the illuminated one, the shadow cast by the latter will be perfectly cylindrical, and its breadth will be equal to that of the diameter of the body. In each of these cases, therefore, the shadow would be infinitely extended.

But if the luminous body be larger than the body illuminated, the shadow will converge as it recedes from the latter until it terminates in a point, the distance of which from the illuminated body will depend on the difference between the diameter of the luminous body and that of the opaque one. The shadow will therefore assume the form of a cone, the base of which is the boundary between the enlightened and dark hemispheres of the opaque body, and the vertex is the extremity of the shadow itself.

When the luminous body is greater than the opaque one, the conical shadow of the latter is encompassed with a fainter divergent shade called the penumbra[2], into which the rays of light can

[1] From *calathus*, a basket.
[2] From *pene*, almost; and *umbra*, a shade or shadow.

come only from certain parts of the luminous body, the rest of the rays being intercepted by the opaque one. This fainter shade increases in breadth as it recedes from the illuminated object in the manner of the shadow cast by an opaque body, whose magnitude exceeds that of the body by which it is illuminated, assumes the same form, and, like that shadow, is of an indefinite length. It is to be observed, that the axis of the penumbra always coincides with that of the principal shadow, and that the nearer any part of the fainter shade is to that shadow, the less light does it receive from the luminous body.

The last case mentioned, or that in which the magnitude of the luminous body exceeds that of the illuminated one, alone concerning the subject of eclipses, and being, moreover, not quite so self-evident as the preceding ones, may probably require illustration; accordingly, let A, fig. 32. be the luminous body, greater than the opaque one B. The convergent rays of light *a b*, *c d*, proceeding from the extreme edges of the former, and in contact with the latter in the same side, meet or intersect each other in the point C. No part, therefore, of the light emitted by the luminous body enters into the cone *b* C *d*, which is, therefore, the dark shadow of the opaque body B. The penumbra is that fainter shadow surrounding the umbra or dark conical shadow which is comprehended between it and the portions *d e*, *b f*, of the rays of light *a d e*, *c b f*, passing from the extreme edges of the luminous body, and touching the opposite extremes of the opaque one. This space, which is partially illuminated by the luminous body, becomes darker as it approaches the conical shadow from which the rays of light are wholly excluded. To an observer, therefore, within the cone *b* C *d*, no part of the luminous

body will be visible, while an observer within the lines *b f*, *d e*, but without the dark cone, will see a part of the luminous body, the rest being hidden by the interposition of the opaque one, and the quantity of the luminous body thus obscured will be greater the nearer the spectator is to the dark cone. If the observer be situated beyond the vertex of the dark shadow as at *g*, he will behold the exterior parts of the luminous body surrounding the dark one on all sides like a lucid ring.

The planets and satellites are all of them opaque bodies illuminated by the Sun; it follows, therefore, that every planet, whether primary or secondary, must cast a shadow towards that point of the heavens which is opposite to that luminary. If, therefore, the Earth or any other planet were equal in magnitude to the Sun, its shadow would be cylindrical, or if it were larger than the Sun, the shadow would assume the figure of a truncated cone, and in either case would be infinitely extended. The Sun, however, being so much larger than any of these bodies, the shadow of every one of them must be of a conical form, growing less and less the farther it recedes from the planet, till it terminates in a point which is the vertex of the cone. The height of the conical shadow of any planet, or the length of the axis of that shadow is greater or less as the planet is at a greater or less distance from the Sun; thus, the conical shadow is longest when the planet is in aphelion, and shortest when it is in perihelion; the primary planets, however, can never eclipse one another, the magnitude of the Sun and the distances of the planets being such, that a primary planet can only eclipse its satellite or be eclipsed by it.

It has been already observed, that an eclipse of the Sun, as it is erroneously but popularly called,

is caused by the intervention of the Moon between the Earth and Sun, whereby his rays are so intercepted that certain portions of the Earth's surface are partially or wholly deprived of his light, causing, in fact, an eclipse of those parts of the Earth where the Moon's shadow or penumbra falls; and that an eclipse of the Moon is caused by her falling into the Earth's shadow, whereby (being an opaque body, and having no light of her own) she undergoes a real eclipse by the interception of the Sun's rays. To exemplify this, let S, fig. 33. be the Sun, E the Earth, and M, *m*, the Moon in two opposite points of her orbit A B. When the Moon is at M, between the Earth and Sun, her conical shadow falling upon the Earth at *a*, will render the Sun totally invisible from that point of the Earth's surface, and its penumbra will cause a partial eclipse to the inhabitants between *b* and *c*. When the Moon is in the opposite point of her orbit at *m*, she will herself be eclipsed by falling into the Earth's shadow. The penumbra of the Earth is disregarded, because its effects in obscuring the Moon cannot be accurately observed by a spectator on the Earth.

An eclipse of the Sun, therefore, can only happen at the time of conjunction, or when the Moon is new, and an eclipse of the Moon at the time of opposition, or when she is full. Now, the Moon being in these situations once in the course of every lunation, if the Moon's orbit coincided with the plane of the ecliptic, a solar and lunar eclipse would happen every month. But since the plane of the Moon's orbit is inclined at an angle of about 5¼ degrees to that of the ecliptic, these phenomena can only take place when the Moon is in or near one of her nodes at the time of new and full Moon.

When the Moon is in either of her nodes at the time of new or full Moon, the Sun, Moon, and Earth, are in the same right line, that is, the line of the Moon's nodes coincides with the line of the syzigies. If, therefore, the Moon be new when this coincidence takes place, her shadow will fall upon the Earth, and there will be a central eclipse of the Sun; if full, the Earth's shadow will fall upon her, and there will be a total and central eclipse of the Moon. If the distance of the Moon from either of her nodes at the time of conjunction be less than 18°, the Sun may be eclipsed, or if she be within 12° of her node at the time of opposition, there may be an eclipse of the Moon, but if the Moon's distance from her node exceed those limits, there can be neither a solar nor a lunar eclipse, for when the Moon is more than 18° from her node at the time of new Moon, her shadow will generally fall either above or below the Earth, and when she is more than 12° from her node at the time of full Moon, she is generally too high or too low in her orbit to pass through any part of the Earth's shadow.

These phenomena I shall endeavour to illustrate by diagram 9, in which the horizontal plane A B C D represents the plane of the ecliptic, and ☊ N ☋ S the plane of the orbit of the Moon. This last is inclined to the plane of the ecliptic, one half being above and the other half below that plane. ☊ is the Moon's ascending, and ☋ her descending. The graduated circle on the plane of the lunar orbit serves to show the distance of the Moon from her node at the time of new or full Moon: it is numbered at every fifteenth degree both ways, from the points *o o* in the line of the nodes, to 90°. At 18° distance from each of the nodes both ways, a small Sun is drawn, and

at 12° distance, a small Moon, for the purpose of showing the limits of solar and lunar eclipses. N and S are the most northerly and southerly points of the Moon's orbit. The point or index I is used for the more readily setting the diagram to any position on the machine, and also for regulating its motion round the centre.

These things being premised, let the index be brought to the first point of Aries, and the line of the nodes made to coincide with the line of the syzigies, in such a manner that ☊ (commonly called the Dragon's Head) may stand over the index I, and ☋ (or the Dragon's Tail) may meet the point D on the plane of the ecliptic. Now, if while the plane of the ecliptic and that of the Moon's orbit are in this situation with respect to each other, the Moon come to her conjunction with the Sun, her shadow must fall upon the Earth, because being in her descending node, or in that point of her orbit in which she crosses the plane of the ecliptic from north to south, she is in the same right line with the Earth and Sun, and consequently there will be a solar eclipse to all those places over which the shadow passes. But, if instead of conjunction, we suppose the Moon to come to her opposition (the relative [illegible] of the two planes still remaining the [illegible] will be a lunar eclipse, because the Mo[illegible] that time in her ascending node, or in [illegible] of her orbit where she crosses the plane [illegible] ecliptic from south to north, she is still in [illegible] right line with the Earth and Sun, and m[illegible] undergo a privation of light by pa[illegible] the Earth's shadow. If, therefore, the [illegible] to remain constantly sta[illegible] in this [illegible] of its orbit while the Moon kept revolving round the Earth, it is obvious that the Sun would be eclipsed

at every change, and the Moon at every full; but the Earth being in constant motion round the Sun, must perform some considerable part of its revolution while the Moon goes once round the Earth.

Let us, therefore, suppose, that while the Moon is performing one synodical revolution in her orbit, the Earth advances about one sign or 30° in the ecliptic, and that the line of the nodes, like the Earth's axis, is constantly carried parallel to itself round the Sun; in this case, if the Moon happen to arrive at her conjunction with the Sun just at the time that the Earth enters the sign Taurus, it will be seen by the graduated circle above described, that the Moon, at the time of the conjunction taking place, is about 30° from her descending node, or about 12° beyond the solar limit, and is, therefore, so much depressed below the plane of the ecliptic, or has so much south latitude, that her shadow will fall considerably below the Earth. If, on the contrary, when the Earth is in this situation, the Moon be in opposition, she will evidently be about 30° from her ascending node, or about 18° beyond the lunar limit, and will, therefore, be too far above the plane of the ecliptic to fall into any part of the Earth's shadow. There can, therefore, be no eclipse of the Sun in the former case, nor of the Moon in the latter. When the Earth has advanced 30° more in her orbit, or has arrived at the beginning of Gemini, the distance of the Moon from the node when new or full is about 30° more, and her latitude being still greater than before, her shadow falls still more below the Earth when new, and [illegible] her above the Earth's shadow when full. When the Earth comes to the beginning of Cancer, if a conjunction of the Moon

take place, she must, at the time of the said conjunction, be in the point S of her orbit, that is, in her greatest south latitude, or at her greatest distance below the plane of the ecliptic. But if she came to her opposition at this time, she must be in the point N of her orbit, where her latitude or height above the plane of the ecliptic is greatest.

If the motion of the Earth be continued in the same manner through the three following signs, we shall see that the Moon, at each succeeding conjunction or opposition, as regularly approaches the right line of the Sun and Earth as she receded from it during the progress of the Earth through the three preceding signs; and if a new Moon happen when the Earth is in the beginning of Libra, the Moon will at that time be in her ascending node, and there will be an eclipse of the Sun: but if the Moon become full while the Earth is in this situation, she must at the time be in her descending node, and must consequently be eclipsed by passing through the Earth's shadow.

When, therefore, the line of the nodes coincides with the line of the syzigies, the Moon is in her nodes at new and full, and in her greatest north and south latitude, or distance from the ecliptic, about her quarters; but when the line of the nodes is at right angles to the line of the syzigies, she is in her greatest north and south latitude, or distance from the ecliptic, at new and full, and in the nodes about her quarters.

It appears, therefore, that if the line of the nodes continued always parallel to itself, there would be just half a year between the conjunctions of the Sun and nodes. But the nodes have a slow retrograde motion, amounting [illegible] and a half each lunation, or about [illegible] minutes in a year, on account of which [illegible] node

meets the Sun about 19 days sooner every year than on the year preceding. If, therefore, the Sun pass by either of the nodes on any particular day, he will pass by the other node in 173 days afterwards, or the same node again in 346 days; thus the nodes perform a complete revolution in the ecliptic in about 18 years, 225 days: this period, however, comprising no complete number of lunations, it cannot become a regular period of eclipses. But in 223 lunations, or in 18 years, 11 days, 7 hours, 42 minutes, 31 seconds, the Sun, Moon, and Earth return so nearly into the same position with respect to each other, that the same node, which at the commencement of this period was in conjunction with the Sun and Moon, will be within 28 minutes of conjunction with them again when this period is completed.

This period, commonly known by the name of the Chaldaic period [1], because for the discovery of it we are indebted to the Chaldeans, was employed by the ancients in predicting the return of eclipses, which they were enabled to do with tolerable accuracy by its assistance; for if to the mean time of the middle of any eclipse, either solar or lunar, we add 18 years, 11 days, 7 hours, 42 minutes, 31 seconds, when leap-year is four times included, or a day less, when it occurs five times in that period, we shall have the mean time of the return of the same eclipse (that is, of the middle time of it) tolerably near the truth. A period, however, much more exact than the preceding, consists of 6890 mean lunations, or 557 Julian years, 21 days,

[1] The Chaldaic period employed by the ancients consisted of 18 years, [illegible] days, 7 hours, 43 minutes, 20 seconds; this period, [illegible] computed by the new [illegible] of De Lambre, [illegible] of Mayer, improved by Mason, comes out, [illegible]

18 hours, 4 minutes, 47 seconds; at the end of which time, the Moon's distance from the position she had relatively to the Sun and Earth at the beginning of this period, will not exceed one minute, four seconds. This period may, therefore, be used in a similar manner to that of the Chaldaic period, and with much greater accuracy, in determining the time of future eclipses. The methods employed by modern astronomers in calculating the recurrence of these phenomena are, however, much more accurate than the preceding, but are, at the same time, more laborious, and such as could not with propriety be treated of in a course of lectures professedly descriptive: those, therefore, who may feel desirous of further information upon this interesting subject, are referred to Ferguson's Astronomy, and other works where the method of calculating eclipses is fully explained.

The number of eclipses in any year cannot be less than two, nor more than seven: in the former case, they will be both solar; and in the latter, there will be five solar and two lunar, which last will both be total. There are sometimes six, but the more usual number is four; two of the Sun, and two of the Moon.

The cause of this variety in the number of eclipses which may happen in the course of a year, is easily accounted for. Although the Sun usually passes by both the nodes only once a year, making four eclipses, yet, if he pass by one of the nodes about the beginning of the year, he may pass the same node again a little before the end of the year; because, in consequence of the retrograde motion of the Moon's nodes already taken notice of, the Sun will come to either of them 173 days after the other, and he may, therefore, return to the same node in about 346 days, thereby making

six eclipses. Again, since twelve synodical revolutions, or 354 days from the eclipse in the beginning of the year, may produce a new Moon before the conclusion of it, and since this new Moon may fall within the solar limit, it is possible for seven eclipses to happen within the year. When the Moon changes in either of her nodes, she cannot come within the lunar limit at the next full, and therefore she cannot be eclipsed; and in six lunar months afterwards she will change near the other node. In this case there cannot be more than two eclipses in the year, and both of the Sun. The ecliptic limits of the Sun being greater than those of the Moon, solar eclipses are more frequent than lunar ones; yet we have more visible eclipses of the Moon than of the Sun, because the former are visible from all parts of that hemisphere of the Earth which is turned towards her; but the latter (as will be shown hereafter) are only seen from that small portion of the hemisphere next him whereon the Moon's shadow falls, and, therefore, there are always more lunar than solar eclipses visible at any given place.

It is worthy of remark, that eclipses of the Sun always begin on the western limb of that luminary, and end on the eastern; but all lunar eclipses come in at the eastern limb, and go off at the western.

In estimating the quantity of an eclipse either of the Sun or Moon, the disc of the body eclipsed is supposed by astronomers to be divided into twelve equal parts, called digits; and as many of these parts as are obscured, so many digits is the Sun or Moon said to be [illegible]psed.

Having thus take[illegible] general view of the doctrine of eclipses, both solar and lunar, I shall proceed to point out a few of the peculiarities of

each, by describing these phenomena separately, beginning with the eclipses of the Sun.

These, we have seen, are caused by the intervention of the Moon between the Sun and Earth. Now, the Moon's orbit being elliptical, and the Earth being placed in one of the foci of the ellipse, it is obvious, that the distance of the Moon from the Earth must vary in every different point of her orbit. When the Moon is at her mean distance from the Earth, her apparent diameter is exactly equal to that of the Sun; when the Moon's distance from the Earth is greater than her mean distance, the apparent diameter of the Sun exceeds that of the Moon; but when the distance of the latter from the Earth is less than her mean distance, her apparent diameter exceeds that of the Sun. When, therefore, the Moon changes about her node, and at her mean distance from the Earth, there will be a total eclipse of the Sun to that small spot whereon her shadow falls. But if the Moon's distance from the Earth, when she changes in her node, be greater than her mean distance, her apparent diameter subtending a less angle than that of the Sun, and her shadow terminating in a point at some distance from the Earth, she cannot hide his whole disc from any part of the Earth's surface; but to those places over which the point of her conical shadow passes, there will be what is called an annular[1] eclipse; that is, the edge of the Sun will appear like a luminous ring surrounding the body of the Moon. If the distance of the Moon from the Earth be less than its mean distance when the change takes place, her apparent diameter being greater than that of the Sun, there will be a total eclipse of that luminary;

[1] From *annulus*, a ring.

and as the Moon's disc will not only cover that of the Sun, but will moreover extend some distance beyond it, the total darkness will last for some few minutes. As, however, the Moon's apparent diameter when largest exceeds that of the Sun when least, by only 2 minutes, 5 seconds of a degree, the total darkness can never continue longer than 4 minutes, 6 seconds, which is the time the Moon takes to move through that space.

The Moon's dark shadow when the Sun is farthest from the Earth, and she is nearest to it, never extends over a circular space upon the Earth's surface exceeding 180 miles in diameter; but her partial shadow or penumbra may then cover a circular space 4900 miles in diameter within every part of which the Sun is seen more or less eclipsed, as the places are more or less contiguous to the centre of this shadow. No solar eclipse, therefore, is universal, or visible throughout the whole of that hemisphere of the Earth which is turned towards the Sun at the time.

When the new Moon or conjunction happens exactly in the node, the shadow (if it touch the Earth) and the penumbra are exactly circular at the instant of the conjunction taking place, because the axis of the shadow at that time passes through the centre of the Earth; but if the conjunction does not happen precisely in the node, the axis does not pass through the centre, and, therefore, the conical shadow is cut obliquely by the Earth's surface, and the section becomes an oval, differing very little from a true ellipse. For the same reason, even when the Moon changes exactly in the node, the penumbra is only circular at the middle of the eclipse: at every other instant it falls obliquely, and, as before observed, becomes elliptical, and the more so as the distance from the middle

of the general eclipse, either before or after, is greater. It is also to be observed, that the greater the obliquity of the penumbra, the larger will be the portion of the Earth's surface involved by it.

An eclipse of the Sun does not present the same appearance to all parts of the Earth where it is visible at the same time: this is owing to the parallax of the Moon, which causes her to appear at the same instant of time in different points of the heavens, as seen from different parts of the Earth, while the parallax of the Sun is too small to produce a similar effect with regard to that luminary: thus, to a spectator who has the Moon in his horizon at any given time, she appears in the heavens at the distance of about a degree, or twice the Sun's apparent diameter, from the place in which she is seen by a spectator who has her in his zenith: whereas the Sun's parallax is so inconsiderable, that at any given moment of time he is seen in the same point of the heavens by all the inhabitants of that hemisphere of the Earth which is enlightened by his rays: hence it happens that an eclipse of the Sun is total in one part of the Earth, and partial at another, at the same time; while to those who live in a still more distant part of the enlightened hemisphere the Sun is not eclipsed at all. This is also the reason why the beginning, middle, and end of a solar eclipse are different at different places.

A solar eclipse does not occur at the same time in all places on the Earth's surface to which it becomes visible, but appears more early to the western parts, and later to the eastern; the direction of the Moon's shadow in passing over those parts of the Earth upon which it falls, being generally from west to east; bearing a little towards the north when the Moon is in or near her ascend-

ing node, and a little towards the south when she is in or near her descending node.

The velocity with which the Moon's shadow traverses the Earth's surface is equal to that of the Moon's motion from the Sun. Now, this motion is about 30 minutes, 30 seconds of a degree per hour, at a mean rate, which is the portion of the lunar orbit through which the shadow passes in that time. But the semidiameter of the lunar orbit is about 60 semidiameters of the Earth; hence one minute of the Moon's orbit is equal to 60 minutes, or one degree of a great circle of the Earth. Now, a degree containing 60 geographical, or 69½ English miles, 30½ degrees are equal to about 1830 geographical, or 2120 English miles, which is the space the shadow describes in one hour.

In order to render the foregoing observations relating to solar eclipses better understood, let S, fig. 34, be the Sun, E the Earth, and M the Moon revolving in her orbit in the direction A M P. The dark space *s*, comprehended between the lines *c* 12, *d* 12, is the conical shadow of the Moon into which none of the direct rays of the Sun can penetrate; and the fainter shade P P, contained between the lines *c a*, *d b*, will be the Penumbra of the Moon, which becomes gradually darker in those parts which are nearer to the conical shadow; those parts about *c* 12, *d* 12, receiving very little of the Sun's light, while the external portions about *c a*, *d b*, experience scarcely any diminution of his influence. In this figure, the Moon is supposed to be at her mean distance from the Earth, and consequently her shadow terminates in a point when it just touches the Earth's surface. Had the Moon been in her perigee, or in that point of her orbit which is nearest the Earth, her shadow

would (as has been already remarked) have covered a circular space 180 miles in diameter, and to all places within that space there would have been a total eclipse, as A, fig. 35. If the Moon had been in her apogee, or in that part of her orbit where she is farthest from the Earth, her shadow would have ended in a point about e, fig. 34, and the Sun would have been annularly eclipsed, as at B, fig. 35. The penumbra, therefore, is obviously a portion of a cone, whose vertex is X, fig. 34, and whose base covers on the Earth's surface a circular space *a* O *b*, only one half of which is visible in the figure, the other half being supposed to be hid by the convexity of the Earth E.

Now, let the Sun's diameter B C be divided into 12 equal parts for the 12 digits, also, let the space 12 O be divided into a like number of equal parts, and from the centre 12, describe 11 concentric circles, marked 11, 10, 9, 8, 7, 6, &c. in the figure. Then to a spectator on the Earth at *b*, the eastern limb *d* of the Moon will seem to touch the western limb B of the Sun, and the eclipse will commence at the place *b*, appearing as at A, fig. 36; but at the same instant an observer at *a*, fig. 34, will see the western limb *c* of the Moon just leaving the eastern limb C of the Sun, as at A', fig. 36. To the inhabitants of the Earth who live on the circle marked 1, fig. 34, the Moon will at the same time obscure one twelfth part of the Sun's disc, and he will appear one digit eclipsed, as at B, or B', fig. 36, according to the situation of the observer on that circle. To those who live on the circle marked 2, fig. 34, the Moon cuts off two twelfth parts of the Sun, as at C, or C', fig. 36. Those who live on the circle marked 3, fig. 34, will have the Sun eclipsed three digits as at D, or D', fig. 36, and so on to the centre 12, fig. 34,

where the Sun is centrally and totally eclipsed, as at N, fig. 36.

It is obvious, from fig. 34, that the Sun is totally or centrally eclipsed to but a very small portion of the Earth at any time, the conical shadow of the Moon covering so small a part of the Earth's surface; while the partial eclipse, or that in which a part only of the Sun is obscured, is visible to all places over which the penumbra extends. It is also evident, that the eclipse is invisible to the large space D D, because from that part of the Earth's surface no part of the Sun is hid by the interposition of the Moon.

The Earth's rotation on its axis being performed nearly in the same direction as the Moon moves in her orbit, to a spectator on the Earth the Moon's motion will appear so much slower than it would do if he were to view it from a point at rest, as his own motion amounts to; but the Moon's motion in her orbit is so much swifter than that of the Earth on its axis, that, although eclipses of the Sun are of somewhat longer duration, on account of the Earth's rotation, yet the time of total darkness can never amount to five minutes of an hour.

When the Moon changes in her node, the centre of the Moon's shadow will pass over the centre of the Earth, and, therefore, the whole penumbra will fall upon the Earth's surface. When the Moon changes about six degrees from the node, almost the whole of the penumbra falls upon the northern hemisphere of the Earth, if the Moon have north latitude, but upon the southern hemisphere, if her latitude be south. When the Moon changes 12° from the node, if she be then north of the ecliptic, rather more than a third part of the penumbra will fall upon the northern part of the

Earth; and a like portion of the penumbra will fall upon the southern hemisphere, if she be south of the ecliptic at the time of the change taking place. Lastly, when the Moon, having north latitude, changes 17 or 18 degrees from the node, the penumbra will just touch the northern part of the Earth's surface* near the north pole; but if her latitude be south, the penumbra will just touch the southern part of the Earth near the south pole.

Having concluded my observations upon solar eclipses, I shall proceed to speak of eclipses of the Moon, which being a much less intricate subject than the former, may, after what has been said respecting these phenomena in a former part of this lecture, be discussed in a few words.

It has already been shown, that an eclipse of the Moon can never happen but when she is in opposition to the Sun, or at the time of full Moon. We have also seen, that, on account of the inclination of the Moon's orbit to the plane of the ecliptic, and the retrograde motion of her nodes, we have not an eclipse of the Moon at every opposition, and that, in point of fact, these phenomena are comparatively of very rare occurrence, because they can only take place when the Moon happens to be full, either in or very near to one of her nodes. Farther to illustrate this subject, let *m*, fig. 34, (where S is the Sun, and E the Earth) be the Moon in opposition to the Sun. When the Moon's eastern limb *x* enters the Earth's shadow at *v*, she begins to be eclipsed, and she is totally eclipsed when her western limb *y* touches the same point of the shadow. At *m* she is centrally eclipsed, being in the middle of the Earth's shadow, and the total eclipse continues till her eastern limb *x* emerges from the Earth's shadow at *w*; and

when her western limb touches the same point, the eclipse altogether ends.

When the Moon goes through the centre of the Earth's shadow, she is exactly in her node, or has no latitude when she comes to her opposition. When the Moon is about six degrees from her node at the time of opposition, she will still pass through the Earth's shadow, and be totally eclipsed in it. When she is full at 12° from her node, she just touches the Earth's shadow, but without entering into it. When, therefore, an eclipse of the Moon is both total and central, its duration is the longest possible, namely, about 3 hours, 57 minutes, 6 seconds, from the beginning to the end, when the Moon is in apogee, or at her greatest distance from the Earth; and about 3 hours, 37 minutes, 26 seconds, when she is in perigee, or nearest the Earth. The diameter of the Moon, like that of the Sun, is supposed to be divided into 12 equal parts, called digits; and when she is said to be any number of digits eclipsed greater than 12, it is to be understood, that she is wholly immersed in the Earth's shadow, which extends so many digits beyond her limb as the number of digits she is said to be eclipsed exceeds 12. The term degrees is now sometimes substituted for digits, each degree being subdivided into 60 equal parts, called minutes; and thus the quantity of an eclipse is, by modern astronomers, frequently expressed in degrees and minutes.

The Moon, even when totally immersed in the Earth's shadow, is sometimes seen of a dusky-red copper colour. That the Moon is at all visible in this situation, may, doubtless, be attributed to the refractive power of the Earth's atmosphere, which being greater near the Earth's surface, on account of its increased density, than at any considerable

height above it, bends or refracts those rays of the Sun which pass nearest the Earth, in such a manner, that some of them falling on the Moon, render her visible; while those rays which pass through the higher parts of the atmosphere, are either refracted in a less degree, or suffer no refraction at all. The red colour, therefore, which the Moon assumes, may be easily accounted for, from her being enlightened by those rays only which pass through the densest part of the Earth's atmosphere, and in which the red or least refrangible rays must, of course, predominate; the violet, or most refrangible rays, being obstructed in their passage through the resisting medium, which the greater momentum of the red rays easily enables them to penetrate.

If the Moon pass in such a manner before any planet or fixed star as to hide it from any part of the Earth, that planet or star is said to suffer an occultation. It is evident, therefore, that all the planets, and many of the fixed stars, namely, those which lie in the Moon's path, are liable to be thus obscured. When the longitude of the Moon is equal to that of any fixed star, an occultation will take place to some parts of the Earth, if the difference of latitude between the Moon and star be less than 57′: if it exceed 1° 37′, no occultation can happen. All those stars whose latitudes do not exceed 6° 36′, may undergo an occultation, as viewed from some parts of the Earth; and those stars, whose latitudes north or south do not exceed 4° 32′, may suffer an occultation from any part of the Earth's surface.

LECTURE XVI.

PHENOMENA OF THE SECONDARY PLANETS, AS SEEN FROM THE EARTH, CONCLUDED. — OF THE TIDES. — PHENOMENA OF JUPITER'S SATELLITES, OF THE SATELLITES AND RING OF SATURN, AND OF THE SATELLITES OF URANUS.

The word tide is used to denote that motion of the water in the seas and rivers, by which they alternately rise and fall twice in the course of about twenty-four hours and three quarters. The tides, therefore, may be more properly considered as terrestrial than lunar phenomena: as, however, for reasons already given,[1] they could not with propriety be described among the phenomena connected with our Earth, I trust that the Moon being (as will hereafter be shown) the principal agent employed in producing them will prove a sufficient apology for introducing the subject in this place.

That these phenomena were not altogether unknown to the ancients, is sufficiently obvious from the allusion made by Homer to the flux and reflux of the waters in his description of the Charybdis; and both Herodotus and Diodorus Siculus mention the daily rise and fall of the water in the Arabian Gulf or Red Sea, the latter describing it as a great and rapid tide. Pytheas of Marseilles, who lived about the time of Alexander the

[1] See lecture 13, page 251.

Great, is the first person who is recorded as having ascribed this motion of the waters to the influence of the Moon. It appears, however, from Quintus Curtius, who describes the amazement of Alexander's soldiers upon seeing their vessels left dry upon the sand on the coast of India, that these phenomena could not have been very generally known among the Greeks. Among the Roman poets, frequent mention is made of the tides, a convincing proof that they were well known to that people; and Pliny, one of the most learned Roman writers, expressly ascribes them to the attraction of the Sun and Moon. The celebrated Kepler is, however, generally allowed the merit of having first assigned the true physical cause of the flux and reflux of the waters of this terraqueous globe. That these phenomena are the effect of the attraction of the Sun and Moon exerted upon the widely-extended waters of the ocean, has since been fully demonstrated by Sir Isaac Newton, who has shown, upon the principle of universal gravitation, that the effects which are observed to take place are precisely such as ought to result from the action of those bodies. The theory of the tides has, however, subsequently received considerable improvement from the labours of Maclaurin, D. Bernouilli, and others, and finally of La Place.

That the tides are principally under the influence of the Moon, is obvious from their always being found to correspond to her motions, and to have a particular reference to her phases, and the position she is in with regard to the Earth. We may, therefore, in the first place, consider the effect of the Moon alone in producing their most general phenomena; namely, that alternate elevation and depression of the surface of the ocean which are found to take place twice in the course of a

lunar day, or about 24 hours and 50 minutes. As, however, the popular method of illustrating these phenomena does not appear to me to be such as to render this interesting subject sufficiently intelligible for many through whose hands this work may be expected to pass, I shall venture upon such a deviation from it as seems to me more likely to be generally understood.

Let A B C, fig. 37, be three bodies of equal magnitudes, placed at equal distances from one another, but at unequal distances from M, which we shall consider as the attracting body, it being quite unnecessary, in this case, to take notice of the reciprocal attraction exerted by the bodies A B C upon M. If the bodies A, B, and C, be all equally attracted by the body M, then, it is evident, they will all move equally fast towards it, and their mutual distances from one another will continue the same; but if these bodies be unequally attracted by M, then that body which is most powerfully attracted will move the fastest, and its distance from the other bodies will be altered. Now, it has been already observed[1], that the power of gravity decreases as the square of the distance increases. By virtue of this law of gravitation, therefore, the body M will attract A more strongly than it does B, and consequently the distance between A and B will be increased. In like manner, B being more strongly attracted than C, the distance between B and C will also be increased: thus, suppose, by the attraction of M, A moves to *a*, B to *b*, and C to *c*; the distance *a b* is greater than A B; and the distance *b c* is likewise greater than the distance B C, but less than *a b*. Again, let us suppose two other bodies

[1] See lecture 5, page 82.

D and E, fig. 38, to be at the same distance from B as A and C, but at right angles to the two latter. The bodies D and E being nearly at the same distance from M as B is, will not recede from each other, but will rather approach nearer to B, by the oblique attraction of M; while, therefore, the bodies A, B, and C, move respectively to *a*, *b*, and *c*, the bodies D, and E, will move respectively to *d*, and *e*, the distance from B, decreasing as they approach M. Now, instead of four bodies, placed at equal distances about the central body B, let us suppose it to be surrounded by a number of bodies, forming a flexible ring, A C D E, fig. 39, and that the whole is attracted by the body M. From what has already been said, it is obvious, that the parts at A of the ring, being nearest to the attracting body, will be more powerfully acted upon than the central body B; the former will therefore advance from A to *a*, while the latter will only move from B to *b*; and the parts of the flexible ring at C being still more remote from M than the central body B, will advance only from C to *c*: as, therefore, the whole gravitates toward M, the parts of the ring about A and C have their distance from the central body B increased; but the parts, D and E, being equally acted upon by the oblique attraction of M, and being nearly at the same distance from M that B is, will approach nearer to B, and the flexible ring will assume the form of an ellipse, *a d c e*, whose greater axis *a b c* produced, would pass through M, and its shorter axis *d b e* will terminate in the points *d* and *e*.

If, instead of being surrounded by a flexible ring, we suppose the central body to be covered with a fluid of equal density, so as to form a fluid sphere about B, this sphere, by the gravitation of

the fluid to M, would, in its approach to that body, be changed to an elliptic spheroid, having its axis directed towards M.

Finally, let us imagine the Earth to consist of a spherical nucleus, entirely covered by the waters of the ocean, and the Moon to be the attracting body; then, if the Moon act upon the Earth according to the principles already laid down, the waters will be accumulated immediately below her, and on the opposite side of the Earth, and depressed at all places, 90° from these points. Hence, the Earth will be thereby changed to an oblong elliptic spheroid, whose axis will be constantly directed towards the Moon; and these accumulated masses of waters will always follow the Moon in her apparent daily revolution about the Earth, producing alternately flood and ebb tide at all places on the Earth's surface except at the extremities of their axis of rotation; and, since the apparent revolution of the Moon is performed once in about 24 hours, 48 minutes, there will be two tides of flood and two of ebb in that time.

Now, although the Earth is not a sphere, but a spheroid, yet it differs so little from a sphere, that the change produced on its real spheroidal figure is very nearly the same as would take place in a true sphere.

The explanation now given of the tides supposes the Earth to be constantly gravitating towards the Moon; but as the Earth revolves round the Sun, it must gravitate towards him also; it may, therefore, be very reasonably asked, how this can possibly be the case when the Moon is full, or in opposition to the Sun? In order to explain this difficulty, it may be necessary to observe, that as the power of gravity combined with the centrifugal force carries the Earth round in its

orbit, and prevents it from falling to the Sun, so do these united powers also carry that luminary round in an orbit, and prevent it from falling to the Earth; and that point between the centre of these two bodies round which they mutually revolve, is called their common centre of gravity, and is as much nearer to the Sun than it is to the Earth, as the quantity of matter contained in the former exceeds that contained in the latter. The Earth, therefore, being so very small in comparison with the Sun, is carried round him in an orbit proportionably larger than that in which he revolves; their common centre of gravity falling entirely within the body of the Sun.[1]

The same law holds between the Sun and the other planets, and also between the primary planets and their respective satellites or moons: our Earth and Moon, therefore, being subject to this law, must, in like manner, revolve round their common centre of gravity; and as the Earth is supposed to contain about 40 times the quantity of matter which is contained in the Moon, the distance of this point from the Earth's centre towards the Moon will be less than the Earth's diameter.

These things being understood, the true cause of the rise of the waters immediately below the Moon, and on the opposite side of the Earth, may be easily explained. Let A D C E, fig. 40, be the Earth, and O the common centre of gravity of the Earth and Moon, round which the Earth will revolve in the same manner as if it were acted upon by an attracting body placed in that centre. Now, all motion being naturally rectilinear, let A A′, B B′, C C′, be the directions in which the points A B C would respectively move if not

[1] The Moon is, in this case, supposed to be removed out of the system.

acted upon by any central body; also, let B *b* be the orbit into which the centre of the Earth is deflected from its tangential direction B B′. Since the attractive force exerted upon the waters at A is as much greater than that which influences the centre of the Earth at B, as the square of O A is less than the square of O B, they must be deflected farther from their tangential direction A A′ than the centre B of the Earth, and instead of describing the orbit A *a*, they will describe the orbit A *x*. In the same manner, the waters at C being acted upon by a force as much less than that which influences the centre of the Earth, as the square of O C is greater than the square of O B, they cannot be deflected as much from their tangential direction C C′ as the centre B of the Earth, and will, therefore, describe the orbit C *z*, instead of the orbit C *c*. Hence an accumulation of waters takes place at the point *x*, in consequence of their rising towards the Moon; and a similar accumulation takes place on the opposite side of the Earth at *z*, in consequence of of their being as it were left behind, or being less deflected than those about the other parts of the Earth, from that rectilinear direction in which all bodies, if acted upon by a projectile force alone, will move; while the waters about *d b e*, or 90° distant from the highest elevations, will sink, both in consequence of their own weight being increased, and because some part of the waters of those places must be drawn off to supply the accumulations about *x* and *z*; the sea, therefore, (supposed to cover the whole Earth) will become an oval, or oblong spheroïd, *d x e z*, whose axis produced passes through the Moon; and, therefore, if the Moon had no real motion of her own in her orbit, but only an apparent motion arising from the rotation of the Earth about its axis, this sphe-

roid, always directed towards the Moon, and following her in her apparent revolution about the Earth, would cause two floods and two ebbs in twenty-four hours; but, because she has a proper motion of her own, from west to east in her orbit, she comes about three-quarters of an hour later to the meridian of any place than she did the day before, and therefore makes two tides of flood, and two of ebb, in about 24 hours, 48 minutes.

We have hitherto considered the Moon as the only agent concerned in producing the tides. The Sun, however, on account of his great magnitude, exerts considerable influence on the waters of the ocean, and has, therefore, a very sensible effect in producing these phenomena; although, by reason of the very small proportion that the Earth's semi-diameter bears to the immense distance of the Sun from the Earth's centre, his disturbing force, compared with that of the Moon, is only in the ratio of 2 to 5. To exemplify this, let us still suppose the Earth's surface to be covered by the ocean, and let A *b* C *d*, fig. 41, be a section of the whole by a plane passing through the Earth's centre; also, let S be the Sun, and M and *m* the Moon at her full and change. If the waters were acted upon by the Moon only, either at M or *m*, the watery spheroid would assume the figure *a b c d*, but, in consequence of the superadded effect of the Sun's attraction, the longest diameter of the spheroid is still more elongated, and the shorter diameter compressed, whereby the actual figure of the ocean becomes A B C D, which, by the Earth's revolution on her axis, produces what are called the spring-tides.

When the Moon is in quadrature, the Sun and Moon acting at right angles to each other, their effects are completely opposed, and the flux and

reflux, instead of being augmented, will be diminished, and these are called the neap-tides. Thus, let *a b c d*, fig. 42, be the figure the waters would have from the action of the Moon alone at M; then, if we suppose them to be also disturbed by the attraction of the Sun at S, those parts of the spheroid about *b* and *d* will be raised to B and D, while the waters which were elevated to *a* and *c* will be depressed to A and C, and the figure of the ocean will be changed to A B C D. Now, if the force of the Sun's attraction upon the waters were equal to that of the Moon, it is obvious, that they would be equally high at all the four points A B C D: this, however, not being the case, but the waters under the Moon being always found to rise above, while those under the Sun are always found to sink below the general level, affords a clear proof that the Moon's influence in raising the tides exceeds that of the Sun.

The effect produced by the gravitation of the waters towards the Sun being so small in comparison of that produced by their gravitation towards the Moon, the solar tides may be regarded as merely increasing or diminishing the lunar tides; the change, therefore, effected by the joint action of these two disturbing forces on any part of the ocean, may be considered as the sum or the difference of the changes which would have been produced by the action of each separately. The two spheroids, which the separate action of the Sun and Moon would have generated, are, consequently, resolved into one figure, differing in form from both; the most elevated parts of which figure follow the Moon in her apparent daily revolution, in consequence of her being the more powerful of the disturbing forces.

According to what has hitherto been said, the tides ought to be highest immediately under the

Moon, and on the opposite side of the Earth, yet, observation proves that the time of high water at any place never happens at the instant of the Moon's passing the meridian of that place, but, mostly, some hours later. Neither do the spring and neap tides take place when the Moon is in syzigy, or in quadrature, but generally a few days afterwards. This difficulty admits of a very easy solution; for the Moon's attraction having communicated a motion of ascent to the waters before her arrival at the meridian, they would continue to rise, even were her influence to cease altogether when she was past that meridian; much more, therefore, must they do so when the attraction is only triflingly diminished, as a small impulse given to a body already in motion, will cause it to move farther than it otherwise would have done. For the same reason, we find, that although the Earth's orbit is elliptical, and the Earth is in perihelion, or nearest the Sun in January, yet, we have not the highest tides at that time, but some weeks later. Generally, however, the tides are highest a little before the vernal equinox, and a little after the autumnal. As, therefore, the Moon's orbit is also elliptical, when the Moon is in perigee or nearest the Earth, at the time of her conjunction or opposition, in February and March, or in September and October, the tides will be very considerably augmented.

Having explained at considerable length, the theory of the tides in general, it will be proper to consider these phenomena under certain modifications, principally arising from the obliquity of the ecliptic, and the inclination of the Moon's orbit to the plane of the equator.

When the Moon is vertical to the equator, the tide that happens when she is above the horizon is

of the same height with the next which takes place when she is below it. But as the Moon declines from the equator, one of the elevations of the water constantly following the Moon, while the other recedes from the equator on the contrary side, the former will describe nearly that parallel to which she is vertical, and the latter will describe a parallel as far distant from the equator in the opposite hemisphere. Thus, the two elevations describe parallels of equal latitudes, but of different denominations. Now, if we suppose any place to be situated in north latitude, it is obvious that the elevation which moves in the northern hemisphere, will come nearer to that place than the elevation which describes a parallel in the southern hemisphere, and since it is high water at any place when either of these elevations passes the meridian of that place, it follows, that the tide produced by one of these elevations, must differ in magnitude from that produced by the other, and that the highest tide will be caused by that elevation which moves in the same hemisphere in which the place is situated. When, therefore, the Moon and the place of observation are both on the same side of the equator, the day tide, or that which takes place while the Moon is above the horizon of that place, exceeds that which is produced when she is below it; because the elevation which immediately follows the Moon, moves on the same side of the equator with the place. When the Moon and the place of observation are on opposite sides of the equator, the elevation which is opposite to the Moon moves on the same side with the place, consequently, the greater tide is produced when the Moon is below the horizon, and the smaller happens when she is above it. The difference between the two tides ought, therefore, to

increase with the distance of the disturbing forces from the equator, and to be greatest when the Sun and Moon are in the tropics, because the two elevations then describe the two circles which are most distant from each other of any they can describe; and observation shows, that in summer the evening tides are higher than the morning, but in winter, the morning tides are higher than the evening.

We have hitherto supposed the surface of the globe to be entirely covered with water, this, however, not being the case, the doctrine of the tides as now explained, can at best only apply to the tides in the ocean, nor will they be found even then altogether to accord with the general theory, since to produce the daily vicissitude of high and low water, would require a longitudinal extent of at least a quadrant of the ellipse. All the phenomena, therefore, which have been described, will be greatly modified by the direction of the shores, the extent of the seas, the width and direction of the channels through which the waters pass, the setting of currents, by winds, and other local circumstances.

In confined seas, such as the Caspian, the Euxine, the Black Sea, the Baltic, and also in lakes of great magnitude, such as those in North America, the rise of the waters is so trifling as to be almost insensible, and even in the Mediterranean, although a sea of considerable extent, the elevation is very small, owing to the narrowness of the passage by which it communicates with the ocean.

Having shown what ought to be the general effects produced by the gravitation of the waters of the ocean to the Sun and Moon, I shall forbear any further remarks upon the tides in particular places, which, although they are sometimes found to be such as even to seem to contradict the gene-

ral theory here laid down, will, upon a minute investigation, be found to be perfectly conformable to that theory, the apparent irregularities being produced by some of those modifying circumstances already alluded to.

The Satellites of Jupiter,

it has already been observed, are four in number. Their mean distances from the centre of their primary in English miles, and the times of their periodical revolutions, have been given in a former lecture.[1]

These bodies always appear nearly in a line parallel to Jupiter's belts, and passing through his centre, but are not constantly seen in the order of their respective distances from that planet. Their general phenomena greatly resemble those of the inferior planets, Mercury and Venus, being sometimes direct, sometimes retrograde, and sometimes stationary. These phenomena will be understood from fig. 43, in which, let I be Jupiter, and the circle *c* W C E, the orbit in which one of the satellites of Jupiter revolves round that planet. Suppose the satellite to be in the point *c* of its orbit, in inferior conjunction with Jupiter, as seen by a spectator on the Earth at O. While the satellite moves from *c* to W, through the western inferior quadrant of its orbit, it will appear to move in a retrograde direction along the line I W, receding from its primary till it comes to W, where it will be stationary at its greatest western elongation from Jupiter. While the satellite moves from W to C, through the western superior quadrant of its orbit, it appears to return towards

[1] See Lecture, pages 69 and 70.

Jupiter, with a direct motion from W to I, and will overtake him at C, when it will be in superior conjunction with him. The satellite will now appear to recede from Jupiter eastwards, and while it is really going through the eastern superior quadrant C E of its orbit, will seem to move along the line I E, its motion still continuing direct, and at E, having attained its greatest eastern elongation, it will again appear stationary. Leaving E, its apparent motion becomes a second time retrograde, and while the satellite proceeds through the eastern inferior quadrant E *c* of its orbit, it appears, as viewed from the Earth, to approach the planet moving along the line E I, and will be again in inferior conjunction when it reaches *c*. The three inferior satellites exhibit similar phenomena. It must, however, be observed, that a satellite will not appear to describe a straight line, unless the plane of its orbit extended pass through the eye of the observer: at all other times it will appear to describe an ellipse, as in fig. 44. Now the orbits of these satellites being inclined to the ecliptic, the plane of any one of them extended would intersect that circle in two opposite points, which are sometimes called the satellite's *geocentric nodes*. When, therefore, the Earth is in either of the geocentric nodes of any satellite, that satellite will appear to describe a right line, but in every other situation of the Earth, the apparent path of the satellite will be an ellipse, the width of which will increase with the distance of the Earth from the geocentric nodes of the satellite, but can never be very considerable, because the angles formed by the orbits of the satellites with the ecliptic are but very small.

In order to determine whether a satellite be at any time in its superior or inferior semicircle, it is

only requisite to notice the direction of its motion, either with regard to the signs of the ecliptic, or with regard to Jupiter. A satellite is in its superior semicircle when its motion is direct, and in its inferior semicircle when its apparent motion is retrograde. Otherwise, when a satellite is seen to the west, or on the right of Jupiter, approaching him; or to the east, or on the left of Jupiter, receding from him, it is in its superior semicircle; and it is in its inferior semicircle when it is seen to the east of Jupiter, advancing towards him, or to the west, receding from him. In both semicircles, a satellite appears to move faster as it approaches the centre of its primary, and slower as it recedes from it.

By reason of the immense distance of Jupiter and his satellites from us, the latter, even at their greatest elongations, always appear very near to their primary. Jupiter being supposed at his mean distance from the Earth, the greatest angular distance of his first satellite is 1 minute, 51 seconds, 6 thirds; of his second, 2 minutes, 56 seconds; of his third, 4 minutes, 42 seconds; and of his fourth, 8 minutes, 16 seconds.

In going from east to west through their inferior semicircle, the satellites of Jupiter sometimes appear to pass over his disc like luminous spots; they are, however, generally most visible at their first entrance upon the disc of the planet, and just before their leaving it, for those parts of Jupiter's disc which lie near the circumference receiving the Sun's rays obliquely, are generally less brilliantly illuminated than the satellites, which, therefore, become the more conspicuous on that account. They are, however, sometimes observed to be less luminous than Jupiter, which is probably owing to some parts of their surfaces not reflecting the light

of the Sun so copiously as other parts. Their shadows may also be sometimes seen either preceding or following the satellites in their passage across the disc of Jupiter. In going through their superior semicircles from west to east, they are eclipsed by passing through the shadow of Jupiter. A satellite may also be hidden behind the body of the planet, without being eclipsed, in which case it is said to suffer an occultation. When Jupiter is in or near his conjunction with the Sun, he is invisible, being hidden behind that luminary, or lost in the splendour of his rays. From the time of Jupiter's first becoming visible after conjunction, till he is nearly in opposition, the immersions only of his satellites can be seen from the Earth. When Jupiter is in opposition, only their occultations can be observed, and from the opposition till near his conjunction, the emersions only are visible. Let S, fig. 45, be the Sun, A B C D the orbit of the Earth, I Jupiter, and the circles marked 1, 2, 3, 4, the orbits of his four satellites. When the Earth is at A, Jupiter is in conjunction with the Sun, and invisible; when the Earth is at B, the first satellite will be observed to enter the shadow of Jupiter at *c*, but its emersion at *d* cannot be perceived, because the body of Jupiter comes between the eye of the observer and that point. When the Earth is at C, Jupiter being exactly in opposition to the Sun, the satellite will pass behind the planet, but neither its immersion at *c*, nor its emersion at *d*, will be visible to a spectator on the Earth, and, therefore, although it will suffer a real eclipse, yet, to an observer on the Earth it will appear to undergo an occultation by passing behind the body of Jupiter. When the Earth is at D, the reverse takes place of what happened when the Earth was at B, the emersion at *d* being now visible, while

the interposition of Jupiter prevents the immersion at *c* from being observed. It appears, therefore, that an immersion of the first satellite and its next subsequent emersion can never be seen by us; but both the immersion and the emersion immediately following of the other three *may* be visible: thus, when the Earth is at B or D, the immersion of the second satellite at *f*, and the emersion at *g*, may both be observed. The dotted lines passing through the centre of Jupiter, show that the satellites may suffer an occultation, or be hidden behind the body of the planet without being eclipsed. When the Earth is at B, the eclipse precedes the occultation, but when the Earth is at D, the occultation takes place before the eclipse.

The three first satellites are always eclipsed when in opposition, but the fourth sometimes passes without undergoing an eclipse, from which, and the very unequal duration of these phenomena, it appears that the planes of their orbits do not coincide with that of the orbit of their primary, for in that case they must always pass through the centre of Jupiter's shadow, and would, consequently, suffer an eclipse of nearly the same duration at every opposition to the Sun. When the line of the nodes of either of the satellites passes through the Sun, that satellite will pass through the centre of the shadow; but as Jupiter goes round the Sun the line of the nodes will be carried out of conjunction with that luminary, and the time of the eclipses will be shortened, the satellite describing only a chord of a section of the shadow instead of the diameter. It is necessary to observe, that the nodes of the satellites here spoken of, are the true nodes, or the points in which the planes of their orbits extended would cut the heliocentric orbit of

their primary, and must be distinguished from their geocentric nodes previously spoken of.

No eccentricity has yet been detected in the orbit of the first satellite, neither is that of the second accurately determined. The third satellite's orbit has an observable eccentricity, which is itself subject to sensible variations, and the line of its apsides has a direct but variable motion. The orbit of the fourth satellite is more eccentric than that of any of the other three, and the line of its apsides has a direct annual motion. The inclination of the orbits to that of their primary, and the position of their nodes, are also subject to variations.

The eclipses of Jupiter's satellites, especially of the first, afford a ready method of determining the longitude of places at land, but as a telescope of considerable power must be used in observing these phenomena, this method cannot be employed at sea, where the violence and irregularities of the motion of a ship render the use of such an instrument for this purpose totally impracticable. The general method of finding the longitude from some celestial phenomenon, the time of which is calculated for any particular meridian, has already been described.[1] I shall, therefore, in this place, offer only a few words respecting the application of that method to the eclipses of Jupiter's satellites. The eclipses of all the satellites that are visible in any part of the world are set down in the Nautical Almanack, the times of the immersions and emersions being accurately calculated for the meridian of Greenwich. If, therefore, an immersion or emersion of a satellite be observed in any place, according to mean time, the difference between

[1] See Lecture XIII. page 216.

this time and the time of the same phenomenon taking place as set down in the Nautical Almanack, is the difference of longitude in time, and this turned into degrees, &c., will be the longitude of the place of observation, which is east or west, as the time at that place is more or less than that of the ephemeris.

From having observed that the immersions of Jupiter's satellites were continually accelerated, while the Earth was advancing towards the planet, and the emersions as gradually retarded, while the Earth was receding from him, Roemer was led to the discovery of the successive propagation of light. It is obvious, that if the motion of light were instantaneous, an immersion would be seen at the same moment of time, whether the Earth were at z or x, fig. 45; but if, on the contrary, light be propagated in time, the further we are from Jupiter, the later will the immersion be perceived, because the light will occupy more time in travelling to us, and, consequently, it will be seen as much sooner when the Earth is at x than when it is at z as the light of the satellite takes to move from x to z. Now, when the distance $x\,z$ (as in the figure) is equal to the radius of the Earth's orbit, it is found, that an immersion which happens when the Earth is in the former position, will be visible 8′ 7″ sooner than when it is in the latter, whence it appears that light must take 8′ 7″ of time to describe a space equal to the semidiameter of the Earth's orbit.

The Satellites of Saturn

Are more numerous than those of any other planet in the System, being, as has been observed in a

former lecture, no less than seven in number. Owing to the great inclination of their orbits to the plane of the orbit of Saturn, they very seldom pass through his shadow, and consequently eclipses of these bodies can very rarely occur. In most other respects the phenomena they exhibit are so similar to those we have already contemplated in the satellites of Jupiter, as to render a particular description of them in this place quite unnecessary.

The Ring of Saturn,

The plane of which coincides with his equator, is inclined at an angle of about 30 degrees to the plane of the orbit of its primary, and like the axis of our earth, always remains parallel to itself. It follows, therefore, that the Sun will shine for 15 years, or during one half of the Saturnian year, upon the north side or upper surface of his ring, and upon its south side or lower surface for a like period. When the Sun passes as it were from the north to the south side of the ring, or from the south to the north side of it, the plane of the ring produced passes through the Sun, and the ring itself becomes invisible. Now this is always found to be the case when the longitude of Saturn is 5 signs 20 degrees, or 11 signs 20 degrees, that is, in the 20th degree of Virgo and the 20th degree of Pisces, which are, therefore, the places of the ring's nodes. The phenomena of Saturn's ring will, however, be best understood from Fig. 46. in which (the Earth's orbit being very small in comparison of that of Saturn, and lying nearly in the same plane) let S be the Sun, A B C D E F G H the orbit of Saturn, and *a b c d* the

orbit of the Earth. When Saturn is at A he is in the ascending node of his ring, which being turned edgewise to the Sun is invisible, and Saturn appears divested of that appendage. As Saturn advances in his orbit from A through B to C, the ring gradually opens and is most open at C. While Saturn is going from C through D to E, the ring gradually contracts in width, and it altogether disappears when Saturn is in its descending node at E. As Saturn moves from E through F to G, his ring again expands, and when he arrives at G, appears as open as it did at C; it then becomes gradually narrower, and when Saturn returns through H to A, his ring once more vanishes as at the first.

A bare view of the figure is sufficient to show that while Saturn is going from A to E, or from the ascending to the descending node of his ring, the northern or upper side of it is illuminated by the Sun, but its southern or lower side is enlightened during the progress of Saturn from C to A, or from the descending to the ascending node of his ring. And when Saturn is in either of these points, the Sun being in the plane of the ring produced, it altogether disappears, because its thin edge only being illuminated, there is not light enough reflected to render it visible.

Since Saturn can only pass through the points A and E once in the course of his revolution round the Sun, or in about thirty of our years, were this the only cause of the disappearance of his ring, it could never be invisible more than twice during that period: it, however, sometimes disappears twice in the same year, which arises either from the Earth's being in the plane of the ring, or from its being on that side of the plane which is turned away from the Sun; for in order that Saturn's

ring may be visible to us, it is not only necessary that one of the sides of the ring should be turned towards the Sun to be enlightened by him, but that our eye should be also sufficiently elevated above the same side of the plane of the ring to receive the light reflected from the ring's illuminated surface. Now the elevation of the eye, requisite for receiving a sufficient quantity of the reflected light to render the ring visible, must depend in a great measure upon the power of the telescope, for Dr. Herschell informs us, that when Saturn was observed through his forty feet reflector, the ring never ceased to be visible. All, therefore, that is meant by the disappearance of the ring in certain situations, is, that in those situations it cannot be seen through a telescope of ordinary power. Dr. Herschell also says, that through the instrument above mentioned, he has sometimes seen the satellites of Saturn extended along the margin of his ring, like bright beads threaded on a string.

Dr. Long mentions an instance related by Whiston, in his Memoirs of the life of Dr. Clark, of a star having been seen by the father of Dr. Clark, through the space between the ring and the body of the planet.

The Satellites of Uranus,

It has been already remarked, revolve with a retrograde motion about their primary, in orbits almost perpendicular to the plane of the ecliptic. When the planes of their respective orbits pass through the Sun they will be eclipsed, but on account of their immense distance from us they

cannot be seen unless Uranus be near his opposition. Eclipses of these satellites were visible in 1799, and again, according to Dr. Herschell, in 1818, when they appeared to ascend through the shadow of their primary, in a direction almost perpendicular to the ecliptic.

LECTURE XVII.

ON COMETS.

HAVING in the preceding lectures given a full description of the bodies which compose the planetary system, investigated the laws by which their motions are governed, and explained the various phenomena which these bodies exhibit to a spectator placed on the surface of our own globe, I shall proceed to treat of the second grand division of my subject; namely,

The Cometary System.

This system consists of the Sun, and an indefinite number of Comets, which, like the planets, circulate about him by the combined action of a centrifugal force and the power of gravity, but differ in many important particulars from those bodies. The Sun, therefore, is the common head of the planetary and cometary systems, under which, being united, they form what is called the Solar System.

Comets, unlike the planets, are only seen occasionally, appear but for a short time, are found in every part of the heavens, and move in all possible directions, so that, although they are really very numerous, scarcely any two of them have been found to pursue nearly the same track. Comets are of various magnitudes; some have been supposed to be much larger than the moon, and even to equal some of the primary planets in size,

nay, if ancient records are to be believed, Comets have appeared almost as large as the Sun, and exceeding that luminary in brightness. The veracity of such accounts may, however, be very justly questioned, since they are entirely unsupported by more recent observations. Comets seldom exhibit any visible disc, but usually shine with a pale dull light like that of Saturn, and are mostly accompanied with a nebulous train or tail turned from the Sun. This train or tail is always transparent, the smallest stars being visible through it, and to common observers forms the distinguishing characteristic of this class of bodies. Hence they are vulgarly denominated blazing stars.

In the infancy of science, when a desire to penetrate into the bosom of futurity was the predominating impulse under which the hosts of the firmament were contemplated; when the stars were considered the dispensers of good and evil to the inhabitants of this nether world; and when the heavens were regarded as that "stupendous book of wisdom to the wise," in which, not only the rise and fall of nations and empires, and all the changes which the political and physical world are doomed to undergo to the end of time, are visibly pourtrayed; but even the fate of every individual is legibly written, — Comets were regarded as the forerunners of the most disastrous events, and war, pestilence, and famine, the overthrow of states, public tumults, private assassinations, and the most violent convulsions of nature, were among the numerous evils with which these supposed prodigies of "dire portent" were imagined to threaten mankind. Nor is it at all surprising that amidst the vicissitudes to which all sublunary affairs are subject, circumstances should

sometimes occur that seemed to confirm these absurd notions, and which it is natural to suppose, the designing professors of judicial astrology would not fail to impose on the credulity of their deluded followers as complete demonstrations of the infallibility of their doctrines.

Without, however, dwelling longer upon such palpable absurdities, let us proceed to examine the various opinions which have been offered by philosophers and astronomers respecting the nature of these bodies, and of the luminous train by which they are generally accompanied.

The ancient Chaldeans are said, upon the authority of Diodorus Siculus and Apollonius Myndius, as related by Seneca, to have considered the Comets as a species of planets, subject to the same laws as other erratic celestial bodies, but moving in much more extended orbits, and consequently, receding so far from the earth as to be invisible during the greatest part of their revolutions. Whether this opinion were the result of actual observation (as it must have been if, as Apollonius farther observes, they were acquainted with the courses described by these bodies) or amounted only to conjecture, it is useless at this distance of time to endeavour to ascertain, and although they are said to have been able to foretell the appearance of Comets, yet, as Dr. Long judiciously observes, "these predictions were probably founded not upon any knowledge of the periodical times of Comets, or any maxims of true philosophy, but upon some fallacious rules of judicial astrology to which that nation was greatly addicted."

That the Comets are bodies resembling the planets, and like them circulating round the central luminary, was also maintained by the Pythago-

reans and the whole of the Italian sect, as we learn from Aristotle, Plutarch, and Seneca; yet Aristotle himself was of a far different opinion, and taught that the Comets were merely exhalations which were raised into the higher regions of the atmosphere, and this opinion was generally adopted by the whole sect of Peripatetics.

Seneca argues strongly against the idea of Comets being nothing but meteors, and declares it his opinion, that they ought to be ranked among the eternal productions of nature; shews that their not moving in the zodiac is no serious objection to their being considered planetary bodies; urges the necessity of collecting all the ancient observations that have been made upon these bodies, in order to determine whether they really have stated periods of revolution or not, and finally prophesies that "the time will come wherein these things, which are now hid from us, will be discovered; which observation and the diligence of after ages will find out; for it is not one age that is sufficient for so great matters. The time will be, when posterity will wonder that we were ignorant of things so plain. One will arise who will demonstrate in what regions of space the Comets wander, why they recede so far from the other planets, how great, and what sort of bodies they are."

It was not, however, till the time of Tycho, that Cometic astronomy was brought to any degree of perfection. That celebrated astronomer, by observations upon the Comet of 1577, conducted with the greatest care, ascertained that it had no diurnal parallax, and that it must therefore, not only be situated far above the limits of our atmosphere, (and consequently could not be a meteor or exhalation, as the Peripatetics imagined,) but that it was at a much greater distance from

the Earth than the orbit of the Moon: thus proving by direct observation, what the most sagacious of the ancient philosophers had at most only conjectured. To the illustrious Tycho, therefore, belongs the honour of having paved the way for the restoration of Comets to the rank of planetary bodies, and this was finally accomplished by Sir Isaac Newton, who, from observations made upon the comet of 1680, combined with his own theory of the planetary motions, has shown that the Comets like planets revolve about the Sun, but that the orbits of the former are very eccentric ellipses extending far beyond the planetary system. The head of a Comet, when examined with a very powerful telescope, appears in general to consist of an opaque ill-defined nucleus encircled by a mass of vapours. The nucleus has different degrees of opacity, and exhibits very different appearances in different Comets, and in some no nucleus can be perceived. The nucleus of the Comet of 1618, a few days after it first became visible, viz. on the 8th of December, is said to have broken into three or four parts of irregular figures, which appeared like so many burning coals, and were observed to change their situation as when a person stirs a fire, a few days after which, they were broken into a great number of small fragments, or, as it were, apparently changed into a cluster of small stars. Sir Isaac Newton supposed the nuclei of Comets to be composed of a very solid and compact substance, capable of supporting without alteration the extremes of heat and cold to which they may be exposed during the course of their eccentrical revolutions about the Sun. Some, however, assert that they are transparent, and that the tails of Comets are nothing else than the beams of the Sun's light transmitted through these transparent heads; and this opinion, which

was held among others by Appian, Cardan, and Tycho, satisfactorily enough accounts for most of the phenomena exhibited by the tails of Comets, concerning the origin of which, however, various opinions have been entertained by astronomers. That the tail of a Comet depends in some way on the Sun is sufficiently obvious from its being constantly turned from that luminary; its gradual increase in length as the Comet approaches its perihelion, when the tail is longest and most luminous, (at which time it is also generally somewhat bent and convex towards those parts to which the Comet is moving;) and from its rapidly decreasing in length as the Comet recedes from the Sun. Kepler imagined that the tail of a Comet was composed of the denser parts of its atmosphere driven away by the impulsion of the solar rays. Des Cartes ascribes it to the refraction of light by the head of the Comet. Sir Isaac Newton supposed that the tail of a Comet consists of a very fine vapour exhaled from the nucleus by the intense heat of the Sun. Various other conjectures have been hazarded upon this subject, some supposing the tails of Comets to be portions of the Sun's atmosphere, others that they are of the same nature with the electric fluid and the aurora borealis. But among all these various conjectures respecting the tails of Comets, the true cause of these surprising phenomena still remains involved in great obscurity; many of those hypotheses which seem even most plausibly to account for the direction of the tail of a Comet, its gradual increase in length as it approaches its perihelion, its again diminishing as it recedes from the Sun, &c., lying open at the same time to such serious objections, as prove them at best to be nothing more than sagacious conjectures, affording no satisfactory solution of the difficulty.

The tail of a Comet sometimes disappears without itself undergoing any actual diminution of magnitude, and merely in consequence of the position which the Comet has in regard to the Sun and Earth, for as the tail is always projected from the Sun, it is obvious, that when a Comet is in opposition, the eye of the spectator being nearly in the same right line which connects the Sun and Comet passing through the middle of the tail lengthwise, the tail will be either wholly concealed by the body of the Comet, or its extremities will appear round the edge of the disc like a fringe of hair, but so mixed with the atmosphere which surrounds the nucleus as scarcely to be distinguished from it, and it is from this appearance that the Comet derives its name. If the eye of the spectator be a little out of that line the tail will appear short, and when it hangs down towards the horizon the Comet is said to be bearded. If the tail of a Comet be viewed sideways the whole length thereof is seen, and if the eye be in the plane of the Comet's orbit continued, the tail appears straight, but when the earth is not in that plane it appears bent.

The tails of Comets are of various lengths. That of the Comet which appeared at the birth of Mithridates, about 130 years before the Christian æra, was 45 degrees long. In A.D. 135, Seneca saw a comet whose tail extended over the whole of the milky way. Longomontanus mentions a Comet that appeared in 1618, the tail of which he asserts to have been above 100 degrees in length; but, according to Kepler, it was no more than 70 degrees, and Newton calculated the tail of the remarkable Comet of 1680 to be at least 80 millions of miles long.

From the nucleus of the Comet of 1665, Heve-

lius observed a darkness to extend along the middle of the tail, which he asserts to have been the shadow cast by the Comet itself. Cassini witnessed a similar appearance in the tail of the Comet of 1680. A darkness was also observed in the tail of the Comet of 1744, which was supposed to arise from the same cause.

The motions of some of the Comets are direct, or according to the order of the signs, and of others, retrograde, or contrary to that order; they all move in ellipses round the Sun, placed in one of the foci, but on account of the very great eccentricity of their orbits, the small portion which a Comet describes when near its perihelion (when it is alone visible,) may without any sensible error be considered as a portion of a parabola.

While a Comet is moving from its aphelion to its perihelion, its motion like that of a planet is continually accelerated, and it is continually retarded while the Comet is going from its perihelion to its aphelion. A Comet's orbit, therefore, being so extremely eccentric, its motion about its perihelion must be prodigiously swift, and accordingly, the Comet of 1680 was calculated by Sir Isaac Newton to move in its perihelion with the immense velocity of eight hundred and eighty thousand miles per hour. This Comet was also remarkable for its very near approach to the Sun, its distance from the surface of which at its perihelion was not above a third part of the semidiameter of that luminary: the heat, therefore, to which it was exposed when in that point of its orbit, must have been to the heat of the summer's Sun to us, in the ratio of about 28,000 to 1; now, supposing this Comet to consist of matter similar to that of which our Earth is composed, its surface, according to Sir Isaac Newton, would have

acquired a degree of heat two thousand times greater than that of red hot iron, and which could not have been exhausted in less than twenty thousand years. As, however, the effect of the Sun's rays in generating heat in the bodies upon which they act, is found by experience to depend greatly upon the constitution of these bodies, we may reasonably doubt whether such an accumulation of heat actually took place in the Comet in question, especially as the period of its revolution is not supposed to exceed 575 years.

The Comet of 1759 deserves particular notice, as the first of which the return had been foretold. Dr. Halley having diligently collected the observations that had been made on different Comets and calculated the elements of twenty-four of them, was induced by the analogy he observed in the elements of those of 1531, 1607, and 1682, to suppose, that it was one and the same Comet which had appeared at these several times, and although there was no less than 15 months difference between the two periods, that from 1531 to 1607, comprising 76 years and 62 days, while the period from 1607 to 1682 consisted only of 74 years 323 days, yet he accounts for this irregularity by ascribing it to the attractions of Jupiter and Saturn, which he supposed altered the form of this Comet's orbit. He was also of opinion that its period, which he had concluded was 75 or 76 years, would probably be lengthened by the action of those planets so as even to exceed the latter term, and that, consequently, the return of this Comet, which, according to the first period, ought to take place in November 1758, or, by employing the second, in August 1757, might not happen till the beginning of 1759.

This interesting subject having engaged the

attention of the celebrated Clairaut (one of the mathematicians that accompanied Maupertuis in his expedition to measure a degree of the meridian in Lapland) he calculated the separate effects of Jupiter and Saturn on the motion of this Comet, and found that its period ought to be lengthened by the action of Jupiter 510 days, and by that of Saturn 100, and would consequently become 76 years 211 days, instead of 74 years 323 days. He therefore concluded, that as the Comet reached its perihelion on the 14th of September 1682, it ought to arrive at the same point of its orbit on the 13th of April 1759. Towards the end of December 1758, the Comet again made its appearance, and reached its perihelion on the 13th of March following, just 30 days before the time mentioned by Clairaut, who by revising his calculation, afterwards reduced his error to 22 days, and finally to 19 days. This Comet may be expected again in 1834.

Although, therefore, very great credit is unquestionably due to the French astronomer for his laborious investigation of this very curious and intricate subject, yet the honour of having first foretold the return of a Comet, is undoubtedly due to our countryman Dr. Halley, who also supposed that the famous Comet of 1680 already mentioned, was the same that was seen in 1106, 531, and in the 44th year before Christ, soon after the murder of Julius Cæsar in the senate-house: and that its period was 575 years. This celebrated Comet is, therefore, probably the same that Homer* alludes to, as it would have appeared in the year 619 B.C.

Notwithstanding the very great number of

* Iliad, iv. v. 75.

Comets which are supposed to belong to our system, the periods of only the two above mentioned are known with any degree of certainty. The Comet that appeared in 1770, according to a very ingenious calculation of its orbit by Lexell, which was afterwards repeated by Burckhardt at the request of the National Institute, completes its revolution in rather more than 5½ years, and ought, therefore, to have returned at least nine times since the year in which it was first observed, but to the great disappointment of astronomers it has never since been seen. It is worthy of remark, that this Comet passed between Jupiter and his satellites, and as it also approached very near the Earth, it is probable, that some remarkable change produced in the form of its orbit by the action of the planets, may have prevented its having been since recognised. As this Comet passed so very near the satellites of Jupiter without producing any change in their orbicular motions or in that of their primary, it may be presumed that Cometary bodies contain very little matter; the same inference may also be drawn from the Comet of 1454, which is said to have eclipsed the Moon, and consequently, must have been very near the Earth, yet produced no sensible effects on the motions of either of these bodies.

The beautiful Comet of 1811, (represented in fig. 47.) was visible longer than almost any other upon record, and would have been seen much longer had its heliocentric motion been direct. The apparent diameter of its nucleus, according to Schroeter, was 1′ 49″, or 10,900 geographical miles. In the centre of this nucleus he also observed another small nucleus much more luminous than the former. The apparent diameter of the latter was 16″·97, or 1,697 miles, and it

seemed to be surrounded by a peculiar kind of atmosphere, and also with a luminous nebulosity. The total apparent diameter of the head of this Comet was 34′ 12″, or 2,052,000 miles, and the greatest apparent length of the tail 18°, or 131,852,000 miles. Burckhardt supposes that the nucleus of this Comet, and perhaps of all others, consists of nothing more than a conglomeration of vapours, probably of so little density as to be transparent.

Of ninety-eight Comets whose elements have been accurately computed, twenty-four passed between the Sun and the orbit of Mercury; — thirty-three between the orbits of Mercury and Venus; — twenty-one between the orbits of Venus and the Earth; — sixteen between the orbits of the Earth and Mars: — three between the orbits of Mars and Ceres; — and one between the orbits of Ceres and Jupiter.

Since the theory of the Cometary motions has been developed, the superstitious fears which the appearance of these bodies formerly excited, have been so entirely dissipated, that Comets are now viewed, even by the vulgar, with scarcely any other sentiment than that of admiration, yet it is a remarkable circumstance, that the same knowledge which has disarmed Comets of their supernatural terrors, has rendered them scarcely less formidable visitors in another point of view, many still supposing that as a great number of the Comets when in perihelion are nearer the Sun than the Earth is, and as these bodies move in all possible directions through the different regions of the planetary system, some of them in approaching the perihelion point of their orbits may probably encounter the Earth itself, or pass so near it as to cause some very great convulsion. That these

terrors are little more than imaginary, a few words will sufficiently evince.

The Comet of 1770, we have already seen, passed between Jupiter and his satellites without creating any visible disturbance in the motions of any of those bodies, and the Comet of 1445, it has also been observed, was found, when so near the Earth as to eclipse the moon, to produce no sensible effect on either; it is obvious, therefore, that Comets possess in themselves so little disturbing power that scarcely any thing short of an absolute shock from one of them could produce any very serious calamity, and since most of the Comets hitherto observed, move in orbits considerably inclined to the plane of the ecliptic, and not one in that plane, the chances against such an event taking place (which could not happen without the Earth and Comet arriving at the same instant, at the same point of intersection) are so numerous as, if not altogether to preclude the possibility of its occurrence, at least to render it extremely improbable. It has been calculated that if a Comet as large as the Earth itself were to pass it at the distance of about 40,000 miles, the only effect produced would be an increase in the periodical revolution of the latter of about two days.

It seems, however, no improbable conjecture that a Comet of considerable magnitude passing very near to a planet might cause unusually high tides. Mr. Whiston carried his thoughts upon this subject so far as even to attribute the universal deluge in the time of Noah to the Earth passing through the tail of a Comet: and as the interval between the time of the deluge, as generally stated by chronologists, and the year 1680, nearly coincides with seven revolutions of the famous Comet

already described, which made its appearance in that year, he imagines that to have been the one through the tail of which the earth passed; and Dr. Halley observes of this very Comet, that "none hath threatened our earth with a nearer appulse than that of 1680. For by calculations I find that November 11^{d} 6^{h} 1′ P.M. that Comet was not above the semidiameter of the Sun to the northward of the way of the Earth. At which time, had the Earth been there, the Comet would have had a parallax equal to that of the Moon, as I take it. This is spoken to astronomers, but what might be the consequences of so near an appulse, or of a contact; or, lastly, of a shock of the celestial bodies (which is by *no means impossible* to come to pass), I leave to be discussed by the studious of physical matters."

With respect to the purposes for which such extraordinary bodies are designed, few conjectures have hitherto been formed that seem entitled to much attention. Dr. Gregory supposed them intended to recruit the exhausted fuel of the Sun, or, by involving the planets in their tails, to restore the moisture which is spent in vegetation and turned into dry earth; and Sir Isaac Newton imagines that the vital principle of our atmosphere, or that subtilest and best part of our air which is necessary to the life of every thing, is derived from Comets. Many other opinions have been entertained respecting the use of these bodies, which from their proximity to the Sun when in perihelion, and their very great distance from that luminary when in aphelion, are generally supposed to experience such extremes of heat and cold as render them wholly unfit for the support of animal or vegetable life. I cannot, however, quit this subject without taking notice of the very

singular hypothesis* advanced by Mr. Whiston. Unwilling, probably, that so numerous a class of bodies (five hundred Comets at least having been observed since the commencement of the Christian æra) should be considered entirely disqualified for the reception of inhabitants of every description, he supposes them appointed by the Almighty as places of punishment for condemned sinners, where they will be tormented by turns with extremes of heat and cold, of which in this state we can of course form no idea. Numerous as Comets are known, and much more numerous as they are generally supposed to be, I would only say in answer to this learned gentleman's opinion, that *if* it be correct, I most sincerely hope (as I believe every real Christian will) that a very great portion, at least, of the most beautiful bodies in the universe may have been created in vain.

LECTURE XVIII.

OF THE FIXED STARS IN GENERAL. — OF THE CONSTELLATIONS.—THE CONSTELLATIONS NORTH OF THE ZODIAC PARTICULARLY DESCRIBED.

OUR attention has hitherto been principally directed to the Sun, with the planets and Comets which revolve round him as their centre of motion, and being entirely destitute of any innate lustre of their own, shine only by reflecting the light of that great luminary. With these bodies, however, those lucid orbs which we are now about to contemplate, are perfectly unconnected. The Fixed Stars constitute by far the most numerous class of celestial bodies, and afford the grandest and most sublime display of the creating power of the Deity. They are called Fixed Stars from their constantly retaining the same position among themselves; for although, by reason of the diurnal and annual motions of our own planet, their situation with regard to the Earth is continually changing, yet the position of any two groups of stars, or of any two stars of the same group, relatively to each other, is at all times found to be the same. This, however, must be considered as a general assertion, to which modern observations (as will hereafter be shown) have put us in possession of many exceptions.

The Fixed Stars may be easily distinguished from the planets by their scintillation or twinkling, while the latter (with the exception of Venus and

Mars when near the horizon) shine with a steady light, and exhibit in general a less luminous appearance. This twinkling is usually ascribed to the intervention of those numerous minute particles of various kinds that are continually floating in our atmosphere. When any one of these particles comes between a fixed star and our eye, the star, by reason of its immense distance, is hidden from our sight, but as the interposed body is instantaneously removed it again becomes visible, and thus, by a perpetual succession of these intercepting particles, the twinkling appearance is produced.

When we take a casual view of the heavens on a clear winter's evening, we are apt to conceive that the number of stars presented to our view exceeds all calculation, yet it has been ascertained that not above a thousand, visible to the naked eye, are at any one time above the horizon. Of these the apparent magnitudes are very different, and this difference, which is obvious to the most superficial observer, may arise either from a diversity in the real magnitudes of the stars, or, which is more likely, from their being placed at unequal distances from us, although in some instances both these causes may combine to produce that difference which is perceived among these bodies, some of which may be both larger and nearer to us than others. Be this as it may, astronomers have distributed the fixed stars, with respect to their apparent magnitudes, into several classes or orders. The brightest and largest are called stars of the first magnitude; the next to these in lustre, stars of the second magnitude, and so on to the sixth, which are the smallest that can be perceived by the naked eye. Those which cannot be discerned without the aid of a telescope are denominated

Telescopic Stars. Very few of the stars of any one of these classes are exactly of the same size and brightness; hence it happens, that many of those stars which are by some astronomers considered of the first magnitude, are by others assigned to the second; and the same uncertainty exists with regard to the other classes: so that, instead of only six classes or magnitudes, we may say that there are almost as many different orders of stars as there are individual stars, there being such an endless diversity in the apparent magnitude, colour, and splendour of these bodies.

The sphere of the fixed stars was by the ancients divided into a number of constellations or assemblages of neighbouring stars, and to every one of these groups they gave the name of some sensible object, to which they fancied they discovered some resemblance in the disposition of the stars that composed the constellation. That this division of the starry hosts is of very high antiquity is evident, since mention is made of several of these fanciful assemblages of stars by ancient authors, both sacred and profane. Thus, in the book of Job, the supposed æra of which is fixed 1513 years B.C., Orion, Arcturus, and the Pleiades are spoken of particularly, and from Homer and Hesiod, who flourished about 634 years later, we gather that the affairs of husbandry and navigation were regulated by observations upon the constellations, several of which are mentioned by name by those authors. It would, however, be in vain to endeavour at this time to ascertain with certainty from whom the Greeks borrowed their sphere — though it is generally supposed that, like most of their astronomical symbols, it was copied from the Egyptians, from whom their knowledge of astronomy was principally derived, —

or to attempt to trace to its origin an arrangement of the stars which probably took place in the earliest ages of astronomy, since the very first cultivators of the science must doubtless have found the necessity of reducing to groups the apparently innumerable multitude of stars that adorn the firmament, in order to distinguish these bodies with regard to their relative situations in the heavens. It is probable that many of the figures of the constellations in the infancy of the science were much more simple than those we have now in use, and that the Greeks changed a great number of them; it is, however, quite certain that some of them were preserved, and have been handed down to us nearly, if not altogether, in the form they received them.

The ancient constellations (as they are now called) were forty-eight in number, or fifty, including Antinöus and Coma Berenices, and were for the most part so delineated as to bring the principal stars into the most conspicuous parts of the figures they were supposed to represent; but as in this distribution of the stars many, from their peculiar situation in the heavens, could not be comprehended in any of those figures, the stars so left out were denominated *unformed stars*. Most of these have been since reduced into new figures by Hevelius, Halley, La Caille, La Lande, and other modern astronomers, so that the number of constellations into which the heavens are at present divided exceeds one hundred; and it is probable that others will yet be invented. They are usually divided into three classes; the first, containing those which are north of the zodiac; the second, comprehending the constellations of the zodiac; and the third consisting of those that are south of it.

The constellations north of the zodiac at present amount to about 38; viz.[1]

URSA MAJOR*, *the Great Bear*; — URSA MINOR*, *the Little Bear*; — CASSIOPEIA*, *Cassiopeia*; — CEPHEUS*, *Cepheus*; — DRACO, * *the Dragon*; — CUSTOS MESSIUM, *the Guardian of the Harvests*; — TARANDUS, *the Rein Deer*; — CAMELOPARDALUS, *the Cameleopard*; — AURIGA*, *the Charioteer*; — LYNX, *the Lynx*; — ANDROMEDA*, *Andromeda*; — PERSEUS ET CAPUT MEDUSÆ*, *Perseus and the Head of Medusa*; — TRIANGULA*, *the Triangles*; — MUSCA BOREALIS, *the Northern Fly*; — GLORIA FREDERICI, *Frederick's Glory*; — PEGASUS*, *the Winged Horse*; — EQUULEUS*, *the Little Horse*; — DELPHINUS*, *the Dolphin*; — LACERTA, *the Lizard*; — CYGNUS*, *the Swan*; — AQUILA ET ANTINÖUS*, *the Eagle and Antinöus*; — SCUTUM SOBIESKI, *Sobieski's Shield*; — SAGITTA*, *the Arrow*; — VULPECULA ET ANSER, *the Fox and Goose*; — LYRA*, *the Lyre or Harp*; — CORONA BOREALIS*, *the Northern Crown*; — HERCULES*, *Hercules*; — OPHIUCHUS VEL SERPENTARIUS*, *the Serpent Bearer*; — SERPENS*, *the Serpent*; — TAURUS PONIATOWSKI, *the Bull of Poniatowski*; — QUADRANS MURALIS, *the Mural Quadrant*; — BÖOTES*, *Bootes*; — MONS MŒNALUS, *the Mountain Mænalus*; — ASTERION ET CHARA, VEL CANES VENATICI, *the Grey Hounds*; — COR CAROLI, *King Charles's Heart*; — COMA BERENICES*, *Berenice's Hair*; — LEO MINOR, *the Little Lion*; — TELESCOPIUM HERSCHELII, *Herschel's Telescope*.

The constellations of the zodiac are 12 in number and are those from which the signs were ori-

[1] The ancient constellations are distinguished from the modern ones by an asterisk, thus *.

ginally named. They now, however, (as we before observed) correspond with them in name only. They are

ARIES *, *the Ram;* — TAURUS *, *the Bull;* — GEMINI *, *the Twins;* — CANCER *, *the Crab;* — LEO *, *the Lion;* — VIRGO *, *the Virgin;* — LIBRA *, *the Scales;* — SCORPIO *, *the Scorpion;* — SAGITTARIUS *, *the Archer;* — CAPRICORNUS *, *the Goat;* — AQUARIUS *, *the Water Pourer* — and PISCES *, *the Fishes.*

The constellations south of the zodiac are 55 in number; viz.

CETUS *, *the Whale;* — OFFICINA SCULPTORIA, *the Sculptor's Shop;* — MACHINA ELECTRICA, *the Electrical Machine;* — FORNAX CHEMICA, *the Chemist's Furnace;* — ORION *, *Orion;* — LEPUS *, *the Hare;* — FLUVIUS ERIDANUS VEL FLUVIUS ORIONIS *, *the River Po or the River of Orion;* — PSALTERIUM GEORGII, *George's Harp;* — BRANDENBURGIUM SCEPTRUM, *the Sceptre of Brandenburg;* — CANIS MINOR *, *the Little Dog;* — MONOCEROS, *the Unicorn;* — ARGO NAVIS *, *the Ship Argo;* — PIXIS NAUTICA, *the Sea or Mariner's Compass;* — CANIS MAJOR *, *the Great Dog;* — MACHINA TYPOGRAPHIA, *the Printing Press;* — COLUMBA NOACHI, *Noah's Dove;* — CELA SCULPTORIS, VEL PRAXITELES, *the Engraver's Tools;* — SEXTANS, *the Sextant;* — HYDRA *, *the Water Serpent;* — CRATER *, *the Cup;* — CORVUS *, *the Crow;* — AVIS SOLITARIA, *the Bird of the Desert;* — CENTAURUS *, *the Centaur;* — LUPUS *, *the Wolf;* — MACHINA PNEUMATICA, *the Air Pump;* — FELIS, *the Cat;* — PISCIS AUSTRALIS *, *the Southern Fish;* — MICROSCOPIUM, *the Microscope;* — LE BALLON AÉROSTATIQUE, *the Air Balloon;* — PHŒNIX, *the Phœnix;* — HYDRUS, *the Water Snake;* — HOROLOGIUM, *the Clock;* —

RETICULUS RHOMBOIDALIS, *the Rhomboidal Net;* — DORADO VEL XIPHIAS, *the Sword Fish;* — EQUULEUS PICTORIUS, *the Painter's Easel;* — PISCIS VOLANS, *the Flying Fish;* — ROBUR CAROLI, *Charles's Oak;* — CHAMÆLEON, *the Chameleon;* — MUSCA AUSTRALIS VEL APIS, *the Southern Fly or Bee;* — CRUX, *the Cross;* — APUS VEL AVIS INDICA, *the Bird of Paradise;* — TRIANGULUM AUSTRALIS, *the Southern Triangle;* — CIRCINUS, *the Compasses;* — QUADRA EUCLIDIS, *Euclid's Square;* — ARA *, *the Altar* — MONS MENSÆ, *the Table Mountain;* — OCTANS HADLEIANUS, *Hadley's Octant;* — PAVO, *the Peacock;* — INDUS, *the Indian;* — TELESCOPIUM, *the Telescope;* — CORONA AUSTRALIS *, *the Southern Crown;* — GRUS, *the Crane;* — TOUCAN, *the American Goose;* — NUBECULA MINOR, *the Lesser Cloud;* — NUBECULA MAJOR, *the Greater Cloud.*

It was not, however, to the constellations only that the ancients gave particular names; smaller collections of stars, and some of the most remarkable single stars, were distinguished in the same manner; thus the cluster of small stars in the neck of the Bull was called the Pleiades; a group of stars in the face of the same figure was denominated the Hyades, the largest star of which has its proper name, Aldebaran; in like manner a bright star in the mouth of the Great Dog is called Sirius, &c. &c. But the best method of distinguishing the stars in the several constellations is that introduced by Bayer, about the year 1603, and consists in applying to them the letters of the Greek and Roman alphabets in such a manner, that the principal star of every constellation is denoted by the first letter of the Greek Alphabet, the next brightest star by the second letter, and so on. Thus the brightest star of the constellation

Draco, is called *α Draconis*; the second brightest, *β Draconis*; the third brightest, *γ Draconis*, &c. It must, however, be particularly observed, that the Greek letters do not indicate the real magnitudes of the stars which they represent, but only the relative magnitudes of those in the same constellation. Thus *α Lyræ* is a star of the first magnitude; *α Ophiuchi*, a star of the second magnitude; and *α Cephei*, a star of the third magnitude. When any constellation contains more stars than the Greek alphabet extends to, the letters of the Roman alphabet are employed, in like manner, to supply the deficiency, and thus every star is much easier distinguished than it would be by a proper name, which (the stars being so numerous) would of course be very difficult to recollect. Another advantage in this method is, that not only the particular star alluded to is immediately known, but the magnitude of that star relatively to the other stars in the same constellation, is at least in a certain degree pointed out. This useful method of noting the stars has, since the time of its inventor, been generally adopted by astronomers, who, when any constellation contains more stars than can be marked by the two alphabets, extend the plan by adding the ordinal numbers, 1, 2, 3, &c.

There is, perhaps, no branch of astronomy more essential than the study of the constellations, which, though too often disregarded by the generality of students in the science, is, in fact, the very first thing to which their attention ought to be directed, as a knowledge of the names and positions of the fixed stars must constitute the basis of all astronomical observations. In order, therefore, to facilitate the acquirement of this

useful knowledge, I shall proceed to give a particular description of all the constellations visible in the latitude of London[1], together with the names, magnitudes, and positions of the principal stars contained in each, accompanied with copious directions for finding them in the sphere of the heavens. These particulars I shall illustrate by figures 48. and 49., which are Celestial Planispheres stereographically projected on the plane of the equinoctial. These Planispheres, although upon a very small scale, contain *all* the constellations already enumerated, in the form and position in which they really occur in the heavens, whereby the embarrassment which generally attends the use of the celestial globe, in acquiring a knowledge of the stars, is completely obviated. In order, however, to prevent confusion, it was found necessary to omit all the stars below the fourth magnitude, and also the Greek and Roman letters by which the particular stars in each constellation are generally distinguished. It is, however, to be observed, that the maps lose nothing of their utility as references in determining the positions of the fixed stars, by the omission of these letters, the instructions which they are intended to illustrate being entirely independent of those characters.

In this descriptive survey of the constellations I shall commence with those which are north of the equinoctial; and of these

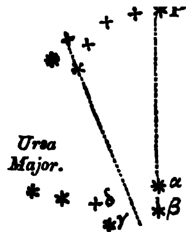
Ursa Major, *the Great Bear*, being the most

[1] From this description of the constellations the reveries of the poets concerning their origin have been excluded to make room for more scientific information. This, it is presumed, is the less to be regretted, as they are to be met with in almost every treatise on the Use of the Globes.

conspicuous, I have made choice of it as a point of reference from which to describe the neighbouring asterisms.

The ancients are said to have represented the constellations of the Bears each under the form of a waggon drawn by a team of horses, and Ursa Major, among country people, is still known by the title of Charles's Wain. It is in some places denominated the Plough, to which agricultural instrument it certainly bears some resemblance.

This constellation contains 87 stars, of which one is of the 1st magnitude, four are of the 2d, three of the 3d, ten of the 4th, &c.: but it is principally distinguished by seven brilliant stars, four of them constituting the body, and the other three the tail; they are disposed as in the annexed figure. The two stars in the body farthest from the tail and marked *α*, *β*, are called the *Pointers*, because if a straight line be supposed to pass through them, and to be continued towards that part of the heavens which is on the convex side of the tail, it will at the distance of the most remote star in the tail from the upper pointer pass nearly through a bright star, P, in the tail of the Little Bear, called *Alruccabah*, or the *Pole Star*. The upper pointer is of the 1st magnitude, though some make it of the 2d, and is called *Dubhe*. The stars in the tail have also particular names assigned them: that which is nearest the body of the animal being called *Alioth*, that in the middle *Mizar*, and the star at the extremity of the tail *Benetnasch*. These three stars are all of the 3d magnitude; the middle one *Mizar*,



however, appears double, having a star of the 5th magnitude just above it, called *Alcor*.

URSA MINOR, *the Little Bear*, contains 24 stars, of which one is of the 2d magnitude, two are of the 3d, four of the 4th, &c. This constellation is chiefly remarkable for its principal star, named *Alruccabah*, or the *Pole Star*, which is situated at the extremity of the Bear's tail. It is called the Pole Star because it is so near the Pole of the world, or that point through which the axis of the Earth produced northward to the sphere of the heavens would pass, that all the stars appear to revolve round it, and as it affords an easy method of determining a ship's course, has been taken notice of by mariners from the earliest ages of navigation; travellers were also formerly in the habit of directing their course through the vast deserts of Arabia by observations upon the stars; it is, however, natural to suppose, that the mariner's compass is now employed as the more convenient guide.

This asterism is easily known by the seven stars, whose magnitudes have been already mentioned: they are disposed nearly in the same form as those of the Great Bear, but in an inverted position, and are inferior to them in brightness. The two stars farthest from the tail, resembling in point of situation the Pointers in the Great Bear, are called the Guards or Wardens of the Pole, the brightest of which, corresponding in position with *Dubhe* in Ursa Major, is denominated *Kochab*.

CASSIOPEIA, called by Ulug Beig, *El Seder*, the Seder Tree, is generally represented as a lady sitting in a chair. The number of stars in this constellation is 55, five of which are of the 3d magnitude, five of the 4th, and the rest smaller. The five principal stars in this asterism, or those

by which it is chiefly distinguished, are arranged something in the form of an irregular W, the upper part of which is turned towards the pole. A line drawn from *Alioth*, the first star in the tail of Ursa Major, by the Polar Star, and prolonged, will conduct us to *Schedir* in the neck of Cassiopeia. This is the first star in the constellation, and forms one of the angular points at the bottom of the W.

CEPHEUS is usually delineated in a sitting posture, having a crown on his head, and holding a sceptre in his left hand. This constellation contains 35 stars, viz. three of the 3d magnitude, seven of the 4th, &c. The left foot of Cepheus nearly rests upon the *Pole Star*, and is easily distinguished by a rather bright star near to *Alruccabah*; the other foot is known by a similar star just under the star in the tail nearest the body of the Little Bear. A line drawn through the *Pointers* in the Great Bear and the *Polar Star*, and prolonged, will pass through a bright star in the left knee of Cepheus. This star forms an isosceles triangle with the *Pole Star* and a bright star in the waist of Cepheus, and a right line drawn from the *Pole Star* through the bright star in the waist of Cepheus, and prolonged, will meet the star *Alderamin* in his right shoulder. A line drawn from the *Polar Star* through the midst of a cluster of stars in the waist of Cepheus, directs us to a star of the 4th magnitude in the throat, and prolonged, passes through three stars in the head, forming a small triangle. A line drawn from *Alderamin* through the star in the throat, and continued to an equal distance on the other side, passes through another star of the 4th magnitude in the left arm of Cepheus.

DRACO, *the Dragon*, is a very extensive constellation, the head and trunk of which is wound

round the Pole of the ecliptic, while its tail divides the Bears and nearly surrounds Ursa Minor.

This constellation contains 80 stars, four of which are of the 2d magnitude, seven of the 3d, and ten of the 4th, &c. Of these stars, one of the 2d magnitude, named *Etanin*, situated in the head of the Dragon, has 51° 30′ north declination, and consequently passes vertically over the inhabitants of London (to which place it is therefore said to be a celestial correspondent) once every twenty-four hours.

A line drawn from the middle star of the three which form the top of the W in Cassiopeia, by the bright star in the waist of Cepheus, and continued to about the same distance on the other side of that star, will lead us to the head of Draco, which will be easily distinguished by four stars forming an irregular square. Two of these, viz. *Etanin* already mentioned, and another called *Rastaban*, are of the 2d magnitude, the former being rather more brilliant than the latter. But the most brilliant star in this constellation is in the tail of Draco, and may be easily distinguished from its situation, viz. between *Mizar* in the tail of Ursa Major and the star immediately below *Kochab* in the Little Bear, and at nearly an equal distance from both.

Custos Messium, *the Guardian of the Harvests*, and Tarandus, *the Rein Deer*, have been formed out of some small stars usually asssigned to Cepheus and Cassiopeia. The former of these constellations was introduced by La Lande, and is represented under the figure of a man having a sickle in his right hand and a staff in his left. The latter was formed by Le Monnier. The stars, about 10 in number in each of them, are mostly invisible to the naked eye.

CAMELOPARDALIS, *the Cameleopard*, is a modern constellation, formed by Hevelius, and contains 48 stars, five of which only are of the 4th magnitude, the rest being all smaller. The most conspicuous star is situated nearly on the arctic circle, in the belly of the figure, the neck of which reaches beyond the Pole, so that the head of the animal is between the tail of the Little Bear and that of the Dragon.

AURIGA, *the Charioteer*, is represented as a man in a sitting or kneeling posture, supporting a goat and two kids on his left hand, and holding a bridle in his right. His head by the apparent diurnal motion of the sphere, passes vertically over England and Ireland once every twenty-four hours. The number of stars contained in this constellation is 66, among which are one of the 1st magnitude, two of the 2d, and nine of the 4th. *Capella*, the most brilliant star in this quarter of the heavens, is situated in the left shoulder of Auriga, or more properly in the belly of the goat, and forms with the *Pole Star*, and *Schedir* in the neck of Cassiopeia, an isosceles triangle. A bright star of the 2d magnitude to the left of *Capella* is in the right shoulder of Auriga. In a line drawn from this star to *Alruccabah*, and at a somewhat greater distance from it than *Capella*, will be found a star of the 4th magnitude, which is the most southern in Auriga's head. If the same line be prolonged in the contrary direction, it will, at about an equal distance on the other side of the star in Auriga's right shoulder, lead to a star of the same magnitude in his right hand, or rather in the wrist. Under *Capella*, and bearing a little to the right, is another star of the 4th magnitude, said to be in the right elbow of the Charioteer; and a little below this again, but inclining rather

to the left, are found two other stars, also of the 4th magnitude, which indicate the Kids. The two other stars, by which this constellation is distinguished, are in the feet. That in the right foot is of the 2d magnitude, and is about as far below the star in the right hand, as that in the right shoulder is above it, but inclines farther to the right, forming an isosceles triangle with the two stars in the shoulders. This star is also included in the constellation Taurus, in which it shews the place of the tip of the Bull's north horn. The star in the left foot of Auriga is of the fourth magnitude: it is rather more distant from the stars in the Kids than *Capella*, and in an opposite direction. A line drawn from *Capella*, through the star in Auriga's right hand, and prolonged, will pass just above a star of the 4th magnitude in the bridle reins.

The LYNX, like the Cameleopard, is one of Hevelius's constellations. It is situated between Ursa Major and Auriga. Of 44 stars contained in this constellation, there are none that exceed the 4th magnitude. One of the most conspicuous stars is situated in the mouth, and is very near the head of Auriga, and two others in the tail are just under the fore-feet of the Great Bear. These all are of the 4th magnitude.

ANDROMEDA is represented on the map by the figure of a woman almost naked, and chained by both wrists to a rock. This constellation consists of 63 stars, three of which are of the 2d magnitude, two of the 3d, and twelve of the 4th, the remaining stars being all below that size.

The chief stars in Andromeda are *Alpheratz* in the head; *Mirach*, in the girdle; and *Almaach*, in the left foot. A line drawn from the *Pole Star*, through that star in Cassiopeia which is nearest the head

of Cepheus, and prolonged to something more than an equal distance on the other side, will pass through the first of these stars, which, it is to be observed, is common to this constellation and Pegasus. In like manner, a straight line drawn from the *Pole Star* to that star in Cassiopea which is nearest it, or farthest from the head of Cepheus, and extended, will lead us to *Almaach*, and about half-way between *Almaach* and *Alpheratz* will be found *Mirach*, from which, if a line be drawn perpendicular to that which connects these three principal stars, it will lead to a star of the 3d magnitude, also in the girdle; near to which is a star of the 4th magnitude, being the most northerly star in this part of the constellation: another star of the 4th magnitude is also found between *Mirach* and *Alpheratz*.

Perseus et Caput Medusæ, *Perseus and the Head of Medusa*, are usually considered as one constellation. Perseus is represented with a sword drawn in his right hand, and the head of Medusa in his left; having a helmet on his head and wings at his ancles. There are in this constellation 59 stars, viz. two of the 2d magnitude, four of the 3d, twelve of the 4th, &c.

A line drawn from *Mirach* to *Almaach* in Andromeda, when produced, will pass through the bright star *Algenib*, of the 2d magnitude in the body of Perseus, on each side of which, and nearly in a straight line perpendicular to the former, is found a star of the 3d magnitude, one in Perseus's left thigh, and the other in his right shoulder. A star of the 4th magnitude in the left shoulder, forms with *Algenib* the base of a triangle, whose vertex is the star in the right shoulder. *Almaach* in Andromeda, and *Algenib*, likewise form the base of a triangle, whose vertex is a bright star of the

2d magnitude, called *Algol*,* situated in Medusa's head.

TRIANGULA, *the Triangles*, are situated nearly between Perseus and Andromeda. This constellation originally consisted of but one triangle; another was however added by Hevelius; the number of stars contained in them is 16, three of which are of the 4th magnitude. The figures are easily distinguished by the disposition of the stars composing the constellation.

MUSCA BOREALIS, *the Northern Fly*, is a small but very distinguishable constellation lying to the left of the triangles. It contains six stars, viz. one of the 3d magnitude, two of the fourth, &c.

A line, drawn from *Algenib* through *Algor*, produced, passes by the chief star, and through the centre of this constellation.

GLORIA FREDERICI, *Frederick's Glory*, is a modern constellation introduced by M. Bode, by whom it was composed out of some unformed stars near the right hand of Andromeda. This constellation is represented on the map by the figure of a sword, with a laurel branch attached to the hilt. It contains 42 stars, four of which are of the 4th magnitude, and will be easily distinguished by its situation, which is about half way between the head of Andromeda and that of Cepheus.

PEGASUS, *the Winged Horse*, contains 89 stars, viz. three of the 2d magnitude, three of the 3d, nine of the 4th, &c.

The stars of the second magnitude in this constellation are *Markab*, *Scheat*, and *Algenib*; they form, with *Alpheratz* in the head of Andromeda, a very large square, by which this asterism is easily recognized. *Markab* is situated in the fore part of the wing; a line from this star to *Alpheratz* is a diagonal of the square, and also the hypothenuse

of a right angled triangle, formed by lines connecting *Scheat* in the leg with *Markab* and *Alpheratz*. *Algenib*, the last in the wing, completes the square. In the mouth of Pegasus is a star of the 3d magnitude, called *Enif*.

EQUULEUS, *the Little Horse*, is in point of figure a very imperfect constellation, the head only being delineated; hence it has been denominated *Equi Sectio*. It contains 10 stars, of which four are of the 4th magnitude. From the position of these stars, which form an irregular quadilateral in front of the Winged Horse's head, this asterism is very easily distinguished.

DELPHINUS, *the Dolphin*, is a very compact constellation, containing 18 stars, five of which are of the 3d magnitude, the rest are all inferior to the 4th. This constellation is very easily distinguished, from the five principal stars forming a conspicuous cluster just in front of Equuleus; four of them, in the face of the Dolphin, are in the figure of a rhomboid, from which the fifth is not far distant.

LACERTA, *the Lizard*, was one of the asterisms added by Hevelius to the old constellations. It contains 16 stars, three being of the 4th magnitude, and the rest smaller. A straight line drawn from *Scheat* in Pegasus to *Alderamin* in Cepheus will pass lengthwise through this constellaion.

CYGNUS, *the Swan*, is situated about midway betwen the Dolphin and the Pole; it contains 81 stars, one of which, called *Deneb*, is of the 1st or 2d magnitude, six are of the 3d, twelve of the 4th, &c. A straight line drawn from *Alruccabah* to the head of the Dolphin will pass through *Deneb*, which is about half way between the two. This star will also be easily recog-

nised as the top of a large cross, formed by the principal stars of this constellation, and by which it may be distinguished without difficulty. A star of the 3d magnitude in the breast of Cygnus is in the centre of the cross, the foot of which is also indicated by a star of the 3d magnitude, situated in the bill of the Swan, and called *Albireo*. The upper arm of the cross points to the head of Draco, and the lower to the head of Pegasus; each of them is distinguished by a star of the 2d magnitude, one being situated in the north and the other in the south wing of the Swan.

AQUILA ET ANTINÖUS, *the Eagle and Antinöus*, are generally considered one constellation, which is intersected by the equinoctial: the whole of the Eagle, with the head, shoulders, and left arm of Antinöus, being situated to the north, and the rest of the asterism to the south of that circle.

It may, therefore, be proper to remark in this place, once for all, that in referring to the planisphere for this or any other constellation which is intersected by the equinoctial, the northern part of the constellation must be looked for in the map of the northern, and the southern part of the constellation in that of the southern hemisphere. This being observed, the continuity of the figures will be easily traced, and the part of any constellation delineated on one of these planispheres corresponding to that represented on the other, may be found by means of the circle of hours surrounding each hemisphere, and pointing out the right ascension in time of the several constellations. The description of any constellation so situated, and the directions for finding it, or any of the stars contained in it, will in future be given in the same manner as if

the asterism under consideration were entirely situated in the northern or southern hemisphere. This constellation contains one star of the first magnitude, called *Athair* or *Altair*, ten of the third, three of the fourth, with a number of smaller, making up in all 74 stars. The Eagle is easily distinguished by three stars situated in the neck, the middle one of which, *Athair*, forms, with *Albirco* in the Swan, and the star nearest to it in the head of the Dolphin, an isosceles triangle, of which *Albireo* may be considered the vertex. The line drawn from the head of the Dolphin to *Athair*, forming the base of this triangle, if produced on the other side of *Athair* passes over a star of the 3d magnitude in the right or south wing of the Eagle. This star, *Athair*, a star of the 3d magnitude in the right shoulder of Antinöus, and another of the same magnitude in his girdle, form nearly a diamond; and a line drawn from the star in the south wing of the Eagle through the star in Antinöus's right shoulder, and produced, conducts to another star also of the 3d magnitude. This last is in Antinöus's right arm. A line drawn from the star in the girdle of Antinöus through that in the Eagle's south wing, prolonged, passes a little above two stars in the tail of Aquila, both of the 3d magnitude. A line drawn from the star in the right shoulder of Antinöus through the star in the girdle continued, leads to a star of the 3d magnitude in his left foot, and in like manner a line drawn from the star in the south wing of Aquila, and crossing the former line in the star in Antinöus's girdle, leads to another star of the 3d magnitude in his knee. These five last mentioned stars therefore form a large X.

SCUTUM SOBIESKI, *Sobieski's Shield*. This constellation is situated near the feet of Antinöus. It

was introduced by Hevelius, and contains only seven principal stars, of which three are of the 4th magnitude, and the rest smaller. Two of the largest stars in this constellation are on the north-east border of the Shield, and the third is near its centre.

SAGITTA, *the Arrow*, is a small constellation north of Aquila, and very near to its left wing. It contains eighteen stars, of which four are of the 4th magnitude; the others are not so large. The shaft of the arrow passes between two of the principal stars; the other two are upon it.

VULPECULA ET ANSER, *the Fox and Goose*. This constellation is situated to the north of Delphinus and Aquila, and is one of those composed by Hevelius out of the unformed stars of the ancients. It contains 35 stars, four of which only are of the 4th magnitude. One of these is in the nose of the Fox, very near to *Albireo* in the Swan, but the exact position of the stars contained in this unimportant asterism is best acquired by a comparison of it with the neighbouring constellations.

LYRA, *the Harp or Lyre*, contains 22 stars, viz. one of the 1st magnitude, two of the 3d, one of the 4th, &c. This asterism is rendered particularly conspicuous by the very brilliant star *Vega*, or *Wega*, which is of the 1st magnitude, and will be found by drawing a line through *Athair*, and the other two stars in the neck of the Eagle; this line produced northwards passes through *Vega*. The other stars, whose magnitudes have been mentioned, are also very bright stars, and with *Vega* form a very brilliant group.

CORONA BOREALIS, *the Northern Crown*, is another very pleasing group of stars, a line from which to the constellation Lyra forms the base of a triangle, whose vertex is the Pole Star. Corona

Borealis contains 21 stars, of which one, called *Alphacca*, or *Gemma*, is of the 2d magnitude; the other principal stars are six in number, and are of the 4th magnitude. This constellation is easily recognised by *Alphacca* and three stars of the 4th magnitude forming a crescent. The other principal stars in this asterism are also conspicuous.

HERCULES occupies that large space in the heavens between the Lyre and the Northern Crown. He is delineated in a kneeling posture, with the skin of the Nemæan lion thrown over his shoulders, grasping a club in his right hand, and holding Cerberus, represented as a serpent with three heads, and the apple-branch, in his left. This constellation contains 113 stars, most of which are very small, there being only seven of the 3d magnitude, 17 of the 4th, &c.

A straight line drawn from the *Pole Star*, so as to pass just half way between *Etanin* and *Rastaban*, in the head of Draco, will direct us to a star of the 4th magnitude, in the left foot of Hercules. The former of the two stars in the head of the Dragon is the vertex of an isosceles triangle whose base is Vega and a star of the 4th magnitude, indicating Hercules's right knee. A line drawn from *Rastaban* through the star in the left foot of Hercules directs to a star of the 4th magnitude in his left knee, and a line parallel to the one last mentioned drawn from the star in his right knee will pass between a star of the 4th magnitude and a smaller one near it, and arrive at a star of the 3d magnitude, all three in the right thigh of Hercules. Between the star of the 3d magnitude in the right thigh and that of the 4th in the left knee is another star of the 4th magnitude, which is in the left thigh, near to which

is a star of the 3d magnitude. A line drawn from *Vega* in Lyra to *Alphacca* in Corona Borealis passes through a group of four stars, two of which are of the 3d magnitude, in the body of Hercules. A line drawn from the star of the third magnitude in the left thigh through the most northerly star in this group, and prolonged on the other side of it, will pass near two stars, of the 3d magnitude, in succession, the first of which is in the hollow under the right arm, the second is in that arm, and if a straight line passing between these stars be drawn from *Alphacca*, it will lead to a star of the 3d magnitude, called *Ras Algethi*, situated in the head of Hercules. The left arm is indicated by four stars of the 4th magnitude in a straight line with one another, the first of which, or that nearest the body, forms, with *Ras Algethi*, the base of an isosceles triangle, having the star under the right arm for its vertex. Very near the first star in the left arm is another star, also of the 4th magnitude, which is situated in the breast of Hercules. The second star in this arm is called *Maasym*. The last of the four stars in the arm forms a small triangle with two other stars of the same magnitude; these are in the left hand, and above them is seen a cluster of stars, of which Cerberus and the Apple Branch are composed: five of the stars in this cluster are of the 4th magnitude.

OPHIUCHUS, VEL SERPENTARIUS ET SERPENS, *Ophiuchus, or the Serpent Bearer and the Serpent*, I shall describe as one constellation, though it is perhaps more frequently divided into two parts, which are considered as distinct asterisms. Ophiuchus was anciently denominated Æsculapius.

This very extensive constellation occupies a large portion of the heavens south of Hercules,

and contains 134 stars, two of which are of the 2d magnitude, fourteen of the 3d, thirteen of the 4th, &c. Of the two stars of the 2d magnitude, one named *Ras Alhague* is in the head of Ophiuchus, and the other is in the neck of the Serpent. *Ras Alhague* is not far from *Ras Algethi* in the head of Hercules, and forms with that star the base of an isosceles triangle whose vertex is *Vega* in Lyra; and if the line from Vega to Ras Algethi, forming one of the sides of this triangle, be produced beyond the base, it will pass near two stars of the 4th magnitude, in the left shoulder of Ophiuchus. The right shoulder is known by two stars of the 3d magnitude, one of which, namely, that farthest from the head, is the vertex of a right-angled triangle whose base is formed by two stars also of the 3d magnitude, situated in the tail of the Serpent. The base of this triangle, produced to a considerable length on the other side of the perpendicular, conducts to two more stars of the same magnitude very near together: these are in the left hand of Ophiuchus. A group of stars of the 3d and 4th magnitudes, just below the Northern Crown, constitute the head of the Serpent. A straight line drawn from *Ras Alhague* through the most northerly star in the left shoulder, when produced, passes through the brightest star in the Serpent, on each side of which, in a straight line, is a star of the 3d magnitude, and very near to it one of the fourth. If from the most northerly of the three just mentioned a line be drawn through the other two, and the most southerly star in the left hand of Ophiuchus, and produced, it will pass through a star of the 3d magnitude in the left knee, and at a considerable distance farther will meet a star of the 4th magnitude in his right foot, very near to which is a

star of the 3d magnitude. In the right leg, a little above the instep, is a star of the 4th magnitude; and higher up, a little below the knee, is one of the 3d. This last forms a triangle with two stars of the 4th magnitude in the Serpent: it is also the vertex of an isosceles triangle, the base of which is formed by the star of the 3d magnitude, in the left knee already mentioned, and another star of the 4th magnitude in the left leg.

TAURUS PONIATOWSKI, *the Bull of Poniatowski*, is a small constellation situated between Ophiuchus and Aquila, introduced by Abbé Poczobut in 1778. It is composed of about seven principal stars, four of which are of the 4th magnitude, and several of inferior magnitudes. The principal stars are for the most part in the Bull's face, near the right shoulder of Ophiuchus.

QUADRANS MURALIS, *the Mural Quadrant*, is a modern constellation, between Draco and the right leg of Hercules. It was composed by La Lande, and consists of about nine stars, all below the 5th magnitude.

BÖOTES is represented as a man in a walking posture, grasping in his right hand a hunting spear, and holding in his left the leash of the two dogs Asterion and Chara, and a reaping hook. This constellation contains 54 stars, viz. one of the 1st magnitude, six of the 3d, eleven of the 4th, &c. It is rendered particularly conspicuous by its principal star *Arcturus*, situated near Böotes's left knee. This brilliant star is the vertex of an isosceles triangle, the base of which is formed by two stars of the 3d magnitude in the shoulders of Böotes, above and between which is another star of the same magnitude in his head. A line drawn from the star in the right shoulder to *Arcturus* passes

through a star of the 3d magnitude, called *Mirac*, and above it, bearing a little to the right, is a star of the fourth magnitude: the girdle of Böotes passes between these two stars. A little above the star in the right shoulder of Böotes is a star of the 4th magnitude, named *Alklurops*, in the point of his spear: a line drawn downwards through these two stars, and produced, leads in succession to two stars of the 4th magnitude in his right leg, below which are two stars of the 3d magnitude, the one in the leg and the other in the instep.

MONS MÆNALUS, *the Mountain Mænalus*, consists of about 11 stars, all below the 4th magnitude, between the feet of Böotes and the Serpent.

ASTERION ET CHARA, VEL CANES VENATICI, *the Grey Hounds*, is one of the modern constellations introduced by Hevelius; it is situated between Böotes and the hind legs of the Great Bear, and consisting only of very small stars, is principally distinguished by the small constellation,

COR CAROLI, *King Charles's Heart*. This constellation is composed of a single star of the 3d magnitude in the collar of Chara. It forms a triangle with *Benetnasch* and the lower star in the side of the square of Ursa Major, nearest the tail. It was made a distinct constellation by Sir Charles Scarborough, physician to Charles II., in honour of King Charles I.

COMA BERENICES, *Berenice's Hair*, is composed of a cluster of 43 stars immediately below the Grey Hounds: ten of these stars are of the fourth magnitude, and the rest are smaller. They are scattered in a very disorderly manner through the constellation, which is however sufficiently remarkable in the Heavens from the number of stars of

the 4th and 5th magnitudes of which it is composed.

LEO MINOR, *the Little Lion*, is situated immediately below the hinder paws of the Great Bear. This constellation contains 53 stars, one of which is of the 3d magnitude, five or six of the 4th, &c. The stars in this asterism are principally divided into three groups, one forming the head and fore-paws of the Lion, the second in which is the star of the 3d magnitude, the body and the third the tail. A line drawn through the two stars in the side of the square in the Great Bear nearest the tail, and produced downwards, conducts to the star of the 3d magnitude, in the belly of Leo Minor, near to which are some stars of the 4th magnitude, and by these the positions of the other stars in the constellation may be easily determined.

TELESCOPIUM HERSCHELII, *Herschel's Telescope*, is a new constellation, introduced in honour of the celebrated astronomer whose name it bears. It is situated in the triangular space contained between the hind legs of the Lynx and the right arm of Auriga, and is composed of about 17 stars, all below the 4th magnitude.

LECTURE XIX.

THE ZODIACAL CONSTELLATIONS, AND THE CONSTELLATIONS SOUTH OF THE ZODIAC, PARTICULARLY DESCRIBED. — AN EASY METHOD OF FINDING WHAT CONSTELLATIONS AND PRINCIPAL STARS ARE ON THE MERIDIAN AT ANY PROPOSED TIME.

HAVING in the last lecture given a full description of all the constellations north of the Zodiac, those which occupy that vast belt or girdle of the starry sphere will next engage our attention.

ARIES, *the Ram*, is the first of the zodiacal constellations. It is situated immediately below Triangula and Musca Borealis, and contains sixty-six stars, viz. one of the 2d magnitude, one of the 3d, two of the 4th, &c. The chief star of Aries is in the forehead, and will be found in a line drawn from the *Pole Star* to *Almaach*, in Andromeda, and produced. To the right of this star, a little more southerly, is one of the 3d magnitude, situated in the Ram's left horn, below, and very near to which is a star of the 4th magnitude, called *Mesarthim*. The other star of the 4th magnitude is in the hind haunch, considerably to the left of the two last mentioned.

TAURUS, *the Bull*, the second of the zodiacal constellations, contains one hundred and forty-one stars, among which are one of the 1st magnitude, one of the 2d, several of the 3d and 4th magnitudes, &c. This constellation is principally remarkable for two clusters of stars, the one in the

face, and the other in the neck of the Bull. The former is called the Hyades, in which is *Aldebaran*, the chief star in the asterism: the latter, denominated the Pleiades, contains a star of the 3d magnitude, named *Alcione*. This group of stars was among the ancients represented by a hen and seven chickens.

Aldebaran will be easily recognized as the vertex of an isosceles triangle, the base of which is formed by *Capella* in Auriga, and *Algol* in Caput Medusæ: it forms the Bull's southern eye, not far from which is a star of the 3d magnitude, indicating his northern eye, and making with the former the base of a small triangle, whose vertex is a star of the 3d magnitude in the nose. These, with the small stars near them, constitute the group above mentioned, called the Hyades. The bright star in the right foot of Auriga, it has already been remarked, is common to that constellation and Taurus, in which latter it forms the tip of the northern horn: the southern horn is indicated by a star of the 3d magnitude; the situation of which is pointed out by a line drawn from the star in the Bull's nose, to *Aldebaran*, and produced. A straight line drawn from the Bull's northern eye to the chief star in Musca Borealis passes just below the Pleiades, which are situated about half-way between those stars.

GEMINI, *the Twins*, the next constellation in the order of the signs, contains eighty-five stars, viz. one of the 1st magnitude, one of the 2d, four of the 3d, sixth of the 4th, &c. The chief stars in this asterism are *Castor* and *Pollux*, or *Apollo* and *Hercules*; they are situated in the heads of the Twins, and each of them bears the name of the Twin in which it is placed. *Castor* is a brilliant star of the 1st magnitude, and is the vertex of an

isosceles triangle, whose base is *Capella* in Auriga, and the star at the extremity of the Bull's southern horn. To the south-east of *Castor*, we find the bright star *Pollux*, of the 2d magnitude. To the south-west are two stars of the 3d magnitude, making a parallelogram with the two former; the more northerly of these is situated in the right knee of Castor, and the other in the left knee of Pollux. Nearly parallel to these, still farther towards the south-west, we find four stars in a line, two of which are of the 3d magnitude. These four stars indicate the four feet of the Twins; a line drawn from the most southerly of which to Pollux passes through a star of the 3d magnitude in Castor's right elbow. A line drawn from this star to Castor passes through a star of the 4th magnitude in the top of his harp or lyre. In a line drawn from this star to the star in Auriga's right shoulder is found a star of the 4th magnitude in Castor's left hand; and in the same right line, but extended on the opposite side of Castor's lyre, is another star of the 4th magnitude, situated in the right shoulder of Pollux.

CANCER, *the Crab*, contains eighty-three stars, seven of which are of the fourth magnitude, the rest are smaller. Of the stars of the 4th magnitude, two situated in the body of Cancer are called the *Asses*; between which is a cluster of small stars denominated *Præsepe*, the Manger. The principal stars in this constellation may be recognized without much difficulty. A line drawn from the right shoulder of Auriga through *Castor* conducts to *Asellus Australis*, the southern Ass: *Asellus Boreus*, the northern Ass, is above it to the left hand, but separated from the southern by *Præsepe*. A line drawn from *Asellus Boreus* to Pollux, passes through a star of the 4th magnitude

in the second northern leg of the Crab. A straight line drawn from Castor through *Asellus Australis* leads to two stars of the 4th magnitude, in the southern claw; not far from which is another of the same magnitude also in the claw. The other principal star is in the first southern leg.

LEO, *the Lion*, is a remarkably fine constellation, consisting of ninety-five stars. Of these, two are of the 1st magnitude, two of the 2d, six of the 3d, thirteen of the 4th, &c. ' The stars of the 1st magnitude are *Regulus*, called also *Cor Leonis*, "the Lion's Heart;" and *Denebola*, in the tail. The latter star forms with *Arcturus* in Böotes the base of an isosceles triangle, whose vertex is *Cor Caroli*; and if the base of this triangle be continued through *Denebola*, it will lead to *Regulus*, in the heart of the Lion. To the right of *Denebola* is a star of the 3d magnitude, situated in the hind haunch, north of which is a star of the 2d magnitude in the back; these two stars are the perpendicular of a triangle nearly right angled, of which *Denebola*, and the star in the Lion's haunch, form the base. A straight line drawn from *Regulus* to the lower star in that side of the square of the Great Bear which is nearest the tail, passes through a star of the 2d magnitude, in the neck of the Lion. To the right of this line, and nearly parallel to it, are found two stars of the 3d magnitude, also in the neck. If from the more elevated of these two stars a line be drawn to the northern claw of the crab, it will pass through an irregular quadrilateral in the head of Leo, composed of two stars of the 3d magnitude and two of the 4th. Between Regulus and the southern claw of the Crab we meet with two stars nearly in a line; the first of these is of the 3d magnitude, and is in the right fore-leg of the Lion; the other, situated in his left fore-leg, is of the 4th magnitude. The hind

legs of Leo are distinguished by a cluster of stars, principally of the 4th and 5th magnitudes.

VIRGO, *the Virgin*. This constellation is generally represented in the figure of a damsel with wings, holding a few ears of corn in her left hand. The number of stars contained in this asterism is one hundred and ten, of which one is of the 1st magnitude, six are of the 3d, several of the 4th, &c. The chief star is called *Spica*, it forms with *Arcturus* in Böotes, and *Denebola* in Leo, a triangle almost equilateral. In the right arm of Virgo is a star of the 3d magnitude, called *Vindemiatrix*; this is situated at about an equal distance from the brilliant star in Böotes and *Denebola*. A straight line drawn from *Arcturus* to *Vindemiatrix*, and produced to about an equal distance beyond the latter, leads to a star of the 3d magnitude, in the northern extremity of the south wing. A line from *Arcturus* to *Spica* passes near a star of the 3d magnitude, a little above the right knee of the Virgin; this star is the vertex of a triangle, whose base is *Vindemiatrix*, and another star of the 3d magnitude, in the south wing, between the left arm and the body of Virgo; and these three stars with a star of the 4th magnitude, in the mouth of Virgo, form a large diamond, near the middle of which is a star of the 3d magnitude, below her girdle. In a line leading from the star in the south wing between the arm and body of Virgo, to the most northerly star in that wing, is a star of the 3d magnitude, in her left arm, near the shoulder. Along the bottom of the garment are three stars of the 4th magnitude; another of the same magnitude is found in each foot of Virgo, and one in her left ankle.

LIBRA, *the Scales*, the seventh zodiacal constellation, contains fifty-one stars, viz. two of the 2d

magnitude, two of the 3d, eight of the 4th, &c. The situation of this constellation in the heavens is easily distinguished by the two principal stars, one of which, named *Zuben el Genubi*, is in the southern scale, and the other, called *Zuben es Chimali*, is in the northern. This last is the vertex of an isosceles triangle, whose base is *Alphacca* in the northern crown, and *Ras Algethi* in the head of Hercules. A straight line drawn from *Vega* in Lyra, to *Zuben es Chimali*, and produced, passes through the chief star in the southern scale. A star of the 3d magnitude, called *Zuben Hakrabi*, in the northern scale, and another of the 4th magnitude in the southern, form a rhomboid with the two stars of the 2d magnitude already described. The other star of the 3d magnitude is below the southern scale.

Scorpio, *the Scorpion*, situated immediately below Ophiuchus, is the eighth zodiacal constellation, and contains forty-four stars, of which one, named *Antares*, is of the 1st magnitude, one is of the 2d, several are of the 3d and 4th, &c. Antares is remarkable for the redness of its light, and may be easily distinguished, from its forming, with *Spica Virginis*, the base of a triangle nearly right angled, of which the perpendicular is the last-mentioned star, and *Arcturus* in Böotes. Between *Antares* and the rhomboid in the Scales are four stars nearly in a line; the most northerly of which is the star of the 2d magnitude, the two next are of the 3d, and the most southerly is of the 4th: the three first are in the head, and the last is in the first south leg of the Scorpion. From the most northerly in the head and *Antares* the other principal stars in this constellation may be easily traced, making with them a figure something resembling a large reaping hook, the blade of which

is formed of the stars constituting the tail of the Scorpion, and the handle by those in the body.

SAGITTARIUS, *the Archer*, is the next of the zodiacal constellations. It contains sixty-nine stars, among which are five of the 3d magnitude, and nine of the 4th; the remainder are of inferior magnitudes. Four stars below one another, but not in a straight line, indicate the bow of Sagittarius. The most northerly of these stars is of the 4th magnitude, and is the vertex of an isosceles triangle, whose base is *Antares* in Scorpio, and the most southerly of the two stars in the right shoulder of Ophiuchus; a little lower down, and bearing to the left, is another star of the 4th magnitude: this is one of the middle stars in the bow, below which, inclining to the right, is a star of the 3d magnitude, in the left wrist of Sagittarius; and still lower, bearing a little to the left, is another star of the 3d magnitude, which is the most southerly in the bow. Near to the star in the left wrist of the Archer is another star of the 3d magnitude, in the head of the arrow. The head of Sagittarius is situated about as far to the left of the most northerly star of the bow as the right foot of Ophiuchus is to the right of it, and is indicated by three stars of the 4th magnitude; below which, and inclining a little to the right, is a star of the 3d magnitude, in the Archer's left shoulder; and under this, in a line with the star in the left wrist, is another star of the 3d magnitude, which last is situated in the body of Sagittarius. The remaining stars in this constellation may be easily traced from the preceding.

CAPRICORNUS, *the Goat*, contains fifty-one stars, three of which are of the 3d magnitude, three of the 4th, &c.: it is, however, principally distinguished by those of the 3d magnitude; two of

these are situated in one of the horns, and the third in the tail. Of the two in the horn, the most southerly is the vertex of an isosceles triangle, whereof the base is *Ras Algethi* in the head of Hercules, and *Antares* in Scorpio: the most northerly is a little above it, and appears double, having a star of the 4th magnitude close to it. The star of the 3d magnitude, in the tail, is the vertex of a triangle almost isosceles, whose base is *Markab* in Pegasus, and *Athair* in the Eagle: a little to the right of this star is one of the 4th magnitude, called *Deneb Algedi*; this is also in the tail.

AQUARIUS, *the Water Pourer*, is situated immediately south of Pegasus and Equuleus, and contains one hundred and eight stars, viz. four of the 3d magnitude, six of the 4th, &c. The principal stars in this constellation may be found with great ease; one of them, situated in the left shoulder of Aquarius, forms, with *Deneb Algedi*, in the tail of the Goat, the base of an isosceles triangle, whose vertex is the southern star in the Goat's horn. A straight line drawn from the upper star in this horn, to the star in the left shoulder of Aquarius, and produced, passes through another star of the 3d magnitude in his right shoulder; a little below which, to the left, will be found a 3d of the same class: this last star is in the Urn, and forms, with two stars of the 4th magnitude, in the same part of the constellation, a small scalenous triangle. The other star of the 3d magnitude, named Scheat, is in the right leg of Aquarius, and forms nearly an equilateral triangle with the star of the 3d magnitude, in the tail of the Goat, and the chief star in the Urn of Aquarius, in whose right foot is a star of the 4th magnitude. A straight line drawn from the star in

the right, through that in the left shoulder of Aquarius, conducts to two stars of the 4th magnitude, the one in and the other near to his left hand: finally, on the left of the two stars, in the tail of the Goat, is found a star of the 4th magnitude, in the left thigh of Aquarius; and if from this star a line be drawn to the principal star in the Urn, it will, at about half-way between the two, pass through *Ancha*, a star of the 4th magnitude in his right side. The stars which indicate the course of the river may be traced with the greatest facility from those stars whose positions have been already described.

Pisces, *the Fishes*, the twelfth and last of the zodiacal constellations, contains one hundred and thirteen stars; of which one is of the 3d magnitude, several are of the 4th, &c. The star of the 3d magnitude, the chief of this constellation, is seated on the knot of the riband by which the fishes are tied. The position of this star in the heavens is ascertained by a line drawn from *Almaach* in Andromeda, to the bright star in the Ram, and produced southwards. A straight line drawn from *Scheat Pegasi* through Markab leads to a star of the 4th magnitude, forming the eye of the more southerly Fish; to the left of which is another star, also of the 4th magnitude; and still farther to the left, inclining a little to the north, a third in the tail of the Fish. Between this and the star in the knot are two or three others of the 4th magnitude. After passing the knot, the riband takes a northerly direction, and in this part also are found one or two stars of the 4th magnitude. The smaller stars in this constellation are not quite so easy to trace, but may, notwithstanding, be found without any great difficulty.

In receding from the Equator towards either of

the Poles certain portions of the starry sphere, about that pole from which the observer retreats, become entirely lost to his view, being perpetually hidden below his horizon. This phenomenon has been fully explained in a former lecture [1], when it was also remarked that those stars which never rise to the inhabitants of any place, are said to be comprehended within the circle of perpetual occultation of that place, and that this circle is as far from the Pole which it surrounds as the place is from the Equator. It follows, therefore, that the circle of perpetual occultation to the inhabitants of London comprehends all those stars that are situated within about 51½° of the South Pole, and which are consequently never visible in our latitudes. I shall, therefore, in describing the positions of the several constellations and principal stars south of the Zodiac confine my observations chiefly to those which are comprehended between the zodiacal constellations, and the circle of perpetual occultation of London above mentioned. This circle is marked on the map of the southern hemisphere, as that of perpetual apparition (comprehending all those stars which never set to the inhabitants of London) is on the map of the northern.

CETUS, *the Whale*, which occupies a greater space than any other constellation in the sphere of the heavens, is situated immediately south of Aries and Pisces, and contains ninety-seven stars, one of which is of the 2d magnitude, ten are of the 3d, several of the 4th, &c.

Menkar, the principal star in this constellation, is situated in the upper jaw, and forms, with the Pleiades and the chief star in Aries, an equilateral

[1] See Lecture VII. pp. 115, 116.

triangle. A straight line drawn from the star in the Bull's northern horn, through *Menkar*, and continued to almost an equal distance on the other side of the latter star, will arrive at a star of the 3d magnitude, called *Deneb Käitos*, in the tail of Cetus, and rather more than half-way between *Menkar* and *Deneb* will pass just above a star of the 3d magnitude, in the belly, named *Baten Käitos.* The same line also passes through two stars of the 3d magnitude, near to *Menkar*; the nearer is situated in the lower jaw, and the other, which is a very singular changeable star, called *Mira*, is in the neck of the Whale. Still nearer to *Menkar* than either of these two, but a little above the line on which they are situated, is another star of the 3d magnitude, just below the Whale's eye. Considerably below *Mira*, a little to the left, are two stars of the 3d magnitude, forming, with two stars of the 4th magnitude, to the right of them, a small irregular square in the breast of Cetus. Below these, in the thigh, is another star of the 4th magnitude. Between *Baten Käitos* and *Deneb* are three stars of the 3d magnitude, forming with *Baten* a quadrilateral in the Whale's belly; and considerably above *Deneb*, to the right, is the most northerly star in the tail; this is also of the 3d magnitude.

Officina Sculptoria, *the Sculptor's Shop*, is a modern constellation, situated directly south of the tail of Cetus, and contains a number of small stars all below the 4th magnitude. This constellation was composed by M. La Caille.

Machina electrica, *the Electrical Machine*, is one of M. Bode's constellations, consisting of twenty-one stars, the two principal of which are of the 5th magnitude. It is situated immediately below the Whale's belly.

FORNAX CHEMICA, *the Chemist's Furnace*, is a constellation composed by M. La Caille, containing two stars of the 3d magnitude, and several smaller ones. The two principal stars in this asterism are nearly north and south of each other, and will be found below the Whale, directly south of Menkar.

ORION, the most brilliant constellation in the heavens, is generally represented by the figure of a man, having a club in his right hand, the skin of a lion in his left, and a sword in his belt. This beautiful asterism contains seventy-eight stars, two of which are of the 1st magnitude, four of the 2d, three of the 3d, sixteen of the 4th, &c. Four of the nine principal stars in this splendid constellation form a trapezoid, at the upper left-hand corner of which is *Betelgeux*, one of the stars of the 1st magnitude: at the right hand upper corner is a star of the 2d magnitude, called *Bellatrix*. The former of these two stars is in Orion's right, and the latter in his left shoulder. In the lower right-hand corner, or in the left foot of Orion, is *Rigel*, the other star of the 1st magnitude. The fourth corner is formed by a star of the 3d magnitude, which is situated in Orion's right knee. About the middle of the trapezoid, in a straight line, inclining to the horizon from right to left, and very near together, are the other three stars of the 2d magnitude: they constitute the belt from which Orion's sword is suspended, in the hilt of which is another star of the 3d magnitude, the remaining one being situated near the extremity of the scabbard. A little north of *Betelgeux* and *Bellatrix*, at nearly an equal distance from both, is a star of the 4th magnitude; in Orion's head, and between this *Bellatrix* and Taurus, are several others, also of the 4th magnitude, in the hide of

the Lion; the exact position of these, however, as also of those which form Orion's club, situated between his head and the feet of Gemini, together with several others in various parts of this constellation, will be easily traced by means of those principal stars, whose situations have been particularly described, — and to find which in the starry sphere it is only necessary to give this general direction; namely, that a straight line drawn from the Pole star to the star in the right heel of Auriga, or the tip of the Bull's northern horn, and produced southwards, passes through the midst of this asterism from north to south.

LEPUS, *the Hare*, is situated immediately south of Orion: it consists of nineteen stars, viz. three of the 3d magnitude, seven of the 4th, &c. One of the stars of the 3d magnitude in this constellation is situated in the right shoulder of the Hare, and is the vertex of a triangle nearly isosceles, having for its base *Rigel* and the star of the 3d magnitude in Orion's right knee. Below this, and a little to the right, is another star of the 3d magnitude, in the right fore thigh; and still lower, to the left, is the other star of the 3d magnitude, situated in the right hind foot of Lepus: these three stars form a small triangle. Between the most northerly of these stars and *Rigel* are two stars of the 4th magnitude: the one in the Hare's right ear, and the other in his snout. Below the star in Orion's right knee are two stars of the 4th magnitude, in the back of the Hare, and farther to the left another, indicating its tail. A little above the star of the 3d magnitude, in the right hind foot, is one of the 4th magnitude, this is in the left hind foot; and to the west of this star, in a line passing a little below the star of the 3d magnitude,

in the Hare's right thigh, is found a star of the 4th magnitude, in his left fore foot.

FLUVIUS ERIDANUS, *the River Po*, is a very extensive constellation, commencing at the left foot of Orion, whence it pursues a winding course to Cetus, and thence assuming a serpentine form, it passes under Fornax Chemica, and Machina Electrica, and is finally lost under the Phœnix, a constellation whose vicinity to the South Pole renders it invisible in our northern latitudes. This is likewise the case with that part of Eridanus which is below Cetus. There are eighty-four stars in this asterism, of which one is of the 1st magnitude, one of the 2d, eight of the 3d, twenty-one of the 4th, &c. The star of the 1st magnitude is called *Achernar;* but being situated at the southern extremity of the constellation it cannot be seen by us. The star of the 2d magnitude is the most southerly of the northern stream. A straight line drawn from *Capella* in Auriga, to *Aldebaran* in Taurus, and produced in a southerly direction, passes through this star, which is about as far distant from *Aldebaran* as the latter is from *Capella*. One of the stars of the 3d magnitude in Eridanus is situated to the north of *Rigel* in Orion: several others of the same magnitude, and a few of the 4th, are found between Orion and Cetus; and by these the course of the northern stream of Eridanus may be easily traced. The southern stream being invisible to us, no particular description of the stars composing it will be given, the principal of which are, however, laid down in the map of the southern hemisphere.

PSALTERIUM GEORGII, *George's Harp*, is a new constellation, and was introduced by a German astronomer, in honour of His late Majesty George III. It consists of about eleven small

stars, and is situated on the northern stream of Eridanus, between Orion, Cetus, and Taurus.

BRANDENBURGIUM SCEPTRUM, *the Sceptre of Brandenburg*, was composed by Geoffroi Kirch, in the year 1688, and consists of about six stars, three of which are of the 4th magnitude. It is situated to the right of the Hare, and the left foot of Orion, and may be easily recognised by its three principal stars, situated in a straight line, and which, if produced northwards, would, after crossing Eridanus, pass through the star of the 3d magnitude, in the nose of the Bull, or the most southerly of the Hyades.

CANIS MINOR, *the Little Dog*, is situated considerably to the left of *Betelgeux* in Orion, and south of the Twins, and contains fourteen stars, viz. one of the 1st magnitude, one of the 3d, &c. *Procyon*, the chief star in this constellation, may be easily found, from its forming an equilateral triangle with *Rigel* in Orion, and the bright star in the tip of the Bull's northern horn. To the right of *Procyon*, and above it, is the star of the 3d magnitude: it is situated in the collar of Canis Minor.

MONOCEROS, *the Unicorn*, is one of Hevelius's modern constellations. It is situated to the left of Orion, below Canis Minor, and contains thirty-one stars, several of which are of the 4th magnitude, and the remainder of inferior orders. The principal stars are distributed through the different parts of the constellation, as follows, viz. one in the eye, one in the nose, one in the left fore foot, one in the right ear, one in the collar, one in the belly, one in the extremity of the tail, and two near the haunch below the tail. The head of the Unicorn may be easily distinguished, but the other parts of the figure cannot be recognised without consider-

able difficulty, and continual reference to the neighbouring asterisms.

Argo Navis, *the Ship Argo*, contains sixty-four stars, of which one is of the 1st magnitude, six are of the 2d, nine of the 3d, nine of the 4th, &c. Only a very small part of this constellation ascends above our horizon, and consequently but few of its principal stars ever become visible to us: among these, however, is one of the 3d magnitude, called Markab: it is situated in the stern of the vessel, nearly due south of Procyon, in Canis Minor, but at a considerable distance from that star. To the left of Markab, and a little more northerly, is another star of the 3d magnitude, also in the stern: these two stars, with a few of the 4th magnitude, are the only considerable ones in this asterism that are ever visible in our latitudes. Its chief star, named *Canopus*, is at the southern extremity of the second oar, and consequently invisible to us.

Pyxis Nautica, *the Mariner's Compass*, is situated in the rigging of the ship Argo, and consists of a few stars, all below the 4th magnitude.

Canis Major, *the Great Dog*, is situated between Orion and Argo Navis, and contains sixty-four stars, among which are one of the 1st magnitude, four of the 2d, two of the 3d, five of the 4th, &c. *Sirius*, the chief star in this constellation, appears more brilliant than any other star in the firmament: it is situated in the snout of the Dog, and forms a triangle almost equilateral with *Betelgeux* in Orion, and *Procyon* in Canis Minor: also if a straight line be drawn from the stars in Orion's belt, to *Markab* in Argo Navis, it will pass through this celebrated star. A little to the right of *Sirius*, and rather lower, is a star of the 2d magnitude, in the left fore paw. A line drawn from *Betelgeux*

to *Sirius*, and produced, passes nearly through another star of the 2d magnitude, situated in the back; this last forms a small triangle with the two remaining stars of the 2d magnitude, one of which is in the right hind haunch, and the other in the tail of the dog. Between the two stars forming the right side of this triangle, is one of the stars of the 3d magnitude; this is in the dog's belly: and considerably to the right is the other, situated in the left hind paw. The stars of the 4th magnitude will be readily found from their position in the figure, one being situated in the head, another in the collar, a third in the right hind foot, &c.

MACHINA TYPOGRAPHIA, *the Printing Press*, is a modern constellation, composed by M. Bode; it consists of about sixteen small stars, none of which exceed the 5th magnitude.

COLUMBA NOACHI, *Noah's Dove*, is a modern constellation, situated immediately below Lepus, between the hind feet of Canis Major, and the beginning of the southern stream of Eridanus. This asterism contains twenty-six stars, one of which is of the 2d magnitude, one of the 3d, two are of the 4th, &c. A straight line drawn from *Procyon* in Canis Minor, to *Sirius*, when produced, passes through the chief star in Columba. The star of the 3d magnitude is situated a little lower, to the left of the former, and from these two stars the positions of the other principal stars in this constellation may be easily traced.

CELA SCULPTORIS, vel PRAXITELES, *the Engraver's Tools*, is a modern constellation, consisting of sixteen stars, none of which exceed the 5th magnitude. It is situated between Columba Noachi and the southern stream of Eridanus.

SEXTANS, *the Sextant*, is also a modern constellation, consisting of forty-one stars, only one of

which exceeds the 5th magnitude. This asterism was formed by Hevelius out of the *Stellæ informes* of the ancient astronomers, and is situated directly below the Lion. The principal star of this constellation is of the 4th magnitude; it is due south of *Regulus*, and about as far distant from it as *Regulus* is from the most northerly in the neck of Leo.

HYDRA, *the Water Serpent*, surpasses in length every other constellation in the heavens, commencing directly south of the Crab, and terminating immediately below the southern scale. This asterism contains sixty stars, among which will be found one of the 2d magnitude, called *Alphard*, one of the 3d, several of the 4th, &c. A straight line drawn from *Bellatrix* in Orion, to *Procyon* in Canis Minor, and continued, passes through a group of four stars of the 4th magnitude in the head of Hydra. A little farther to the left, and rather more southerly, is another star of the 4th magnitude, in the neck of the serpent, to the south-east of which, and nearly on a line with the chief star in the Sextant, is found another star also of the 4th magnitude, which last is situated in a flexure of the neck. South of this star, a little inclining to the west, is *Alphard*, in the heart of Hydra, the most brilliant star in the constellation. Nearly south of the chief star in the Sextant, is another star of the 4th magnitude, in the belly of Hydra, and if a line be drawn from *Alphard* to this star, and continued to about an equal distance on the other side, it will lead to another star of the 4th magnitude. Passing nearly in a south-easterly direction from this star, below two stars, one of the 3d, the other of the 4th magnitude, in the constellation Crater (hereafter to be spoken of), we come, at a considerable distance from them, to two

stars of the 4th magnitude in succession; and pursuing the serpentine direction of Hydra, (which after ascending a little proceeds nearly due east,) we come to a star of the 3d magnitude, (the only one of that class in the constellation,) situated to the south of *Spica Virginis.* Farther to the left, and a little more southerly, is one more star of the 4th magnitude, which is the last star of consequence in this asterism.

CRATER, *the Cup*, is situated immediately below the hind feet of Leo and the head of Virgo, and contains thirty-one stars, one of which is of the 3d magnitude, several are of the 4th, and the remainder of inferior magnitudes. The star of the 3d magnitude, and one of the 4th, called *Alkes*, are situated in the foot of the Cup, and will be easily recognised, being those two stars beneath which the Hydra was traced: the other stars in this constellation will be most easily found by tracing their position relatively to the principal stars in

CORVUS, *the Crow*, which lies east of the Cup, between Virgo and Hydra, and consists of nine stars, three of which are of the 3d magnitude, two of the 4th, &c. One of the stars of the 3d magnitude is situated in the feet of the Crow, and is the vertex of a small triangle, whose base is formed by the other two stars of the 3d magnitude, one of which indicates the left, and the other the right wing; the latter is called *Algorab*, and is the more distant from the Cup. One of the stars of the 4th magnitude is in the Crow's head, and the other in the bill.

AVIS SOLITARIA, *the Bird of the Desert*, is a modern constellation, situated on the tail of Hydra, south of Libra, and the feet of Virgo. It con-

tains eighteen stars, all of them below the 4th magnitude.

CENTAURUS, *the Centaur*, is one of the old constellations, and occupies a very considerable space below the tail of Hydra. It consists of thirty-five stars, *viz.* one of the 1st magnitude, three of the 2d, six of the 3d, nine of the 4th, &c. The star of the 1st magnitude is situated in one of the fore feet, and is therefore too near the South Pole to be visible to the inhabitants of Great Britain; and this is likewise the case with most of the other principal stars in this constellation. The only stars of importance in the Centaur that ever rise above our horizon, are one of the 2d magnitude in the left shoulder of the Centaur, one of the 3d in his right shoulder, and four stars of the 4th magnitude, all of which are in his head.

LUPUS, *the Wolf*, is situated to the east of Centaurus, and contains twenty-four stars, among which are one of the 3d magnitude, several of the 4th, &c.

MACHINA PNEUMATICA, *the Air Pump*; and

FELIS, *the Cat*, are modern constellations, situated between Hydra, Centaurus, and Argo Navis. They consist entirely of small stars, none of them exceeding the 5th magnitude.

PISCIS AUSTRALIS, *the Southern Fish*, is one of the ancient constellations, and contains twenty-four stars, one of which, called *Fomalhaut*, is of the 1st magnitude: it is situated in the eye of the Fish, and may be easily found, being due south of *Scheat Aquarii*, and at no great distance from that star; it may also be recognised by its forming a small triangle with two stars of the 3d magnitude, one of which is in the Fish's back, and the other in its belly. There are also some stars of the 4th magnitude in this constellation, whose

positions may be easily traced from those already described.

Microscopium, *the Microscope;* and

Le Ballon Aerostatique, *the Air Balloon,* are modern constellations, situated directly south of Capricornus, between Piscis Australis and the hind legs of Sagittarius. The stars contained in these constellations are all below the 4th magnitude.

We come now to those circumpolar stars which never ascend above our horizon, concerning which I shall content myself with making a few brief observations, chiefly with regard to their relative situation in the celestial sphere.

The Phœnix, unlike most of the modern constellations, was not formed out of the *stellæ informes* of the ancients, neither was it included in any of the ancient constellations, but was known as a distinct asterism to the Arabian astronomers from a very early period, under the name of the Griffin or Eagle. It is situated between Officina Sculptoria and the extremity of the southern stream of Eridanus.

Hydrus, *the Water Snake,* is a modern constellation, and is found between the Phœnix and the South Pole.

Horologium, *the Clock,* and

Reticulus Rhomboidalis, *the Rhomboidal Net,* are situated to the east of Hydrus, between it and

Dorado vel Xiphias, *the Sword Fish,* which is a small asterism situated at the southern Pole of the ecliptic, and extending lengthways towards the southern stream of Eridanus.

Equuleus Pictorius, *the Painter's Easel,* is immediately south of Columba Noachi, lying between it and the southern Pole of the ecliptic.

Piscis Volans, *the Flying Fish*, is situated on the antarctic circle, in a line drawn from Pixis Nautica to the South Pole of the World.

Robur Caroli, *Charles's Oak*, is south of Machina Pneumatica, a line drawn from which to the South Pole passes through Robur Caroli and

Chamælion, *the Chamelion*; the latter is, therefore, south of the Oak.

Musca Australis vel Apis, *the Southern Fly* or *Bee*, is a very small constellation, situated at the foot of

Crux, *the Cross*, an asterism containing five stars, one of which is of the 1st magnitude, two are of the 2d, one is of the 3d, and one of the 4th.. By this brilliant constellation those who navigate the southern hemisphere can as readily find the Antarctic Pole as we can the Arctic by the Great Bear, for the two stars which respectively indicate the summit and the foot of the Cross, having nearly the same right ascension, are always in a line with the South Pole, and consequently become the *load-stars* or *pointers* of the south. For the same reason it follows that the constellation must be almost vertical at the moment it passes the meridian; and as it is well known to the inhabitants of the southern regions at what hour of the night in different seasons the "bright Cross of the south" is erect or inclined, it is to them a time-piece that advances very regularly almost four minutes a day. Professor Humboldt, in his interesting "Travels in South America," has given a very animated account of this remarkable asterism.

Apus vel Avis Indica, *the Bird of Paradise*;

Triangulum Australis, *the Southern Triangle*; and

Circinus, *the Compasses*, are three small mo-

dern constellations situated between the head of Lupus and the South Pole.

QUADRA EUCLIDIS, *Euclid's Square*, is directly south of Scorpio, between it and Triangulum Australis.

ARA, *the Altar*, is situated immediately below the tail of Scorpio.

MONS MENSÆ, *the Table Mountain*, is a modern constellation, situated between the South Pole of the World and that of the ecliptic.

OCTANS HADLEIANUS, *Hadley's Octant*, will be easily recognised on the map from its situation in the South Pole of the World.

PAVO et INDUS, *the Peacock and the Indian*, are sometimes considered as one constellation. They are situated between Sagittarius and Octans Hadleianus. The most brilliant star in the asterism forms the eye of the Peacock. The Indian is usually represented in an erect posture with an arrow in his left hand, and a quiver at his back.

TELESCOPIUM, *the Telescope*, and

CORONA AUSTRALIS, *the Southern Crown*, are situated between the Peacock and the bow of the Archer.

GRUS, *the Crane*, and

TOUCHAN, *the American Goose*, are found in succession, in a line drawn from the tail of Piscis Australis to the South Pole of the Ecliptic.

NUBECULA MINOR, *the Lesser Cloud*, is situated between the tail of Hydrus and Mons Mensæ.

NUBECULA MAJOR, *the Greater Cloud*, is found between Mons Mensæ and the head of Dorado.

In concluding this account of the constellations it is proper to remark, that the description I have now given of each, applies to it only when on or near the meridian. Thus, in describing the position of the stars in Orion's belt, I took occasion to observe

that they were situated "*in a straight line inclining to the horizon from right to left*:" now this is only true when Orion is very near the meridian, for when rising in the east, these three stars are almost in a perpendicular direction, and when setting in the west, they become perfectly horizontal. The same may be observed of the two principal stars in Canis Minor, and similar instances are to be met with in most of the other constellations.

In order, therefore, to facilitate the application of the astrographical instruction which I have now presumed to offer, I shall, in concluding this lecture, give a very simple method of finding, by means of the celestial planispheres, what constellations and principal stars culminate, or come to the meridian at any given time. These planispheres or maps of the heavens, as was before observed, are projected on the plane of the equinoctial, which circle, therefore, becomes a boundary to each of them, and upon it the right ascension is marked both in time and degrees. The meridians or hour circles (which in this projection would have been straight lines), with the exception of the colures, have been omitted to avoid confusion, and in the room of them a silk string is fixed in the centre of each planisphere. This string possesses all the advantages of a movable meridian, and can be brought to coincide with any point on the circumference of the map at pleasure. The declination is found from that quadrant of the equinoctial colure which is graduated for that purpose. The secondaries and parallels to the ecliptic, or circles of longitude and latitude, are represented, the former by dotted arcs from the Pole of the ecliptic to the periphery of each map, and the latter by dotted circles drawn concentrically to those Poles. On these Planispheres, each of which presents one

half of the ecliptic, the Polar Circles and Tropics are also inserted, the former at 23½, and the latter at 66½ degrees from the Poles.

Now, in order to find what constellations and principal stars are on the meridian at any given time, first let the proposed day be sought on the calendar of months laid down on the machine, against which will be found the sun's longitude or place in the ecliptic for that day, and observing whether this be among the signs marked "NORTHERN," or "SOUTHERN SIGNS," find the corresponding point on the map of the northern or southern hemisphere accordingly; the silk string extended over that point will cut the Sun's right ascension, either in time or degrees, amongst the divisions on the circumference of the map. Secondly, consider whether the proposed time be before or after noon; — if the former, move the string backwards so many hours as the proposed time wants of noon; but if the latter, advance the string forwards so many hours as the given time is past noon. Finally, letting the string remain in this position, notice what degree on the periphery of the planisphere is now cut by it, and extend the silk string in the centre of the other planisphere over the corresponding degree on its circumference. The strings thus disposed form a complete meridian on the two maps, extending from the North to the South Pole, and passing over all the constellations and principal stars which culminate at the given hour. Those stars, however, on the map of the southern hemisphere, between the circle of perpetual occultation and the South Pole, over which the meridian passes, will be invisible, being below our horizon; and those stars which are in the line of the meridian, produced through the Pole in the northern hemisphere

to the opposite side of the circle of perpetual apparition, will come to the meridian below the Pole, and be above the horizon at the proposed time.

For example, suppose it were required to find what stars come to the meridian on the 1st of February at 8 o'clock in the evening? The Sun's longitude on that day is found to be 10 signs 13 degrees, or 13 degrees of Aquarius, which being a southern sign, must be looked for in the ecliptic on the map of the southern hemisphere, then extending the silk string over this point to the circumference of the map, his right ascension is found to be 315°, or twenty-one hours; from which moving the string forwards eight hours, because the proposed time is 8 o'clock in the evening, or eight hours past noon, we come to 75°, or five hours, which is the right ascension of all those stars south of the equinoctial, over which the string in this situation passes; then bringing the string in the centre of the map of the northern hemisphere to the corresponding division on the circumference of that map, it will in like manner pass over all those stars north of the equinoctial having the same right ascension. All the stars, therefore, both in the northern and southern hemisphere, whose right ascension is 5 hours or 75 degrees, culminate at eight o'clock in the evening on the 1st of February. Amongst these, proceeding from the North Pole southwards, the principal are, CAPELLA in Auriga, and RIGEL in the left foot of Orion. The two brilliant constellations, Auriga and Orion, therefore, are both on the meridian; the former occupying the zenith, the brilliant Capella being only 5½ degrees south of that point. The other constellations culminating with them are Camelopardalis, between Auriga and the Pole, and Lepus with Columba Noachi, south

of Orion, the latter being the most southerly asterism at that time above the horizon. On the meridian below the Pole, are found Ursa Minor and Draco, the head of the latter being at no great elevation above the horizon[1].

Having, by the simple method now pointed out, ascertained what constellations are on the meridian, at the time of his examining the heavens, and made himself perfectly familiar with the names and positions of the principal stars contained in them, the student may proceed to contemplate the neighbouring asterisms, the relative position of which may be found in the Planispheres by inspection; and thus, in the course of a few evenings, at different seasons of the year, devoted to this delightful study, he may without difficulty become familiar with every constellation and principal star, which is ever visible in our latitudes.

The Ecliptic and Equinoctial, however, being the most important circles of the sphere, the student should by no means neglect to make himself acquainted with their true position in the heavens as early as possible, a task which he will easily accomplish by the assistance of the Planispheres.

[1] Many of the most important problems, usually worked by the Celestial Globe, may be solved with much more ease and expedition, and with sufficient exactness for general purposes, by means of these Planispheres. These, for obvious reasons, could not with propriety be introduced in the Lectures, but will be found in the Appendix, together with many other useful Problems, systematically arranged under the head of "PROBLEMS AND EXERCISES ON THE ASTRONOMICON."

LECTURE XX.

ON THE PARALLAX AND DISTANCE OF THE FIXED STARS.—ON THE PROPER MOTION OF THE FIXED STARS, ARISING FROM THE PROGRESSIVE MOTION OF THE SOLAR SYSTEM.—ON NEW AND VARIABLE STARS.—ON DOUBLE STARS.—ON NEBULÆ AND THE MILKY WAY.—OF THE DIFFERENT SYSTEMS OF THE HEAVENS.—OF THE PTOLEMAIC SYSTEM.—OF THE EGYPTIAN SYSTEM.—OF THE COPERNICAN SYSTEM.—THE TRUTH OF THE COPERNICAN SYSTEM DEMONSTRATED.—OF THE DIURNAL MOTION OF THE EARTH.—OF THE EARTH'S ANNUAL MOTION.

The fixed stars, even when examined with the most powerful telescope, do not exhibit any sensible disc, but appear merely like luminous points in the heavens; a striking proof of the immense distance of these bodies. This is, however, still more effectually demonstrated, in the failure of every attempt that has hitherto been made, to discover their annual parallax, or the angle subtended at any of them, by the diameter of the earth's orbit.

Dr. Bradley, whose observations were conducted with so much accuracy, as to lead him to the discovery (as we have already seen) of the aberration of light, was entirely unsuccessful in his endeavours to ascertain the annual parallax. The method he employed for this purpose was the same that had been previously practised by Hook, Flamstead, and other astronomers, and consisted in observing the meridian altitudes of the stars, when the earth was in opposite points of its orbit; these observed altitudes were then corrected by refraction, aberration, and nutation: the difference in

the place of the stars, after these corrections, would be the parallax sought; and Dr. Bradley asserts, that if this parallax had amounted to a single second, or two at the most, he should certainly have detected it, in the numerous observations he made upon stars near the zenith, especially upon the star *Etanin*, or γ Draconis. From the uncertainty, however, of the refraction, aberration, and nutation, this method is obviously subject to great disadvantages. To obviate which, Dr. Herschel has proposed a method by means of double stars, which is not only free from all liability to these errors, but is besides of such a peculiar nature, that the parallax, even if it should not exceed the tenth part of a second, may still become visible, and be ascertained to a much greater degree of accuracy than by any other method which has yet been devised. Of this method, the first hint of which was given by Galileo, my limits will not permit me to give a particular description; it however appears to me to proceed upon assumptions too arbitrary to be generally admitted; neither does it seem to have led to any more satisfactory results, respecting this grand object of enquiry, than had been previously obtained: Dr. Herschel's observations, like all others which have yet been made for the purpose of discovering the annual parallax, only tending to prove that the diameter of the earth's orbit, in length one hundred and ninety millions of miles, does not subtend a sensible parallactic angle at the nearest fixed star.

Mr. Mitchell has proposed an enquiry into the probable parallax and magnitude of the fixed stars, from the quantity of light derived from them, and the peculiar circumstances of their situation. In this investigation, Mr. Mitchell sets out with supposing the stars, at a medium, to be equal to our

sun in magnitude and natural brightness; and that Saturn, in opposition, exclusive of his ring, is equal in light to the most luminous fixed star; and then proceeds to enquire, what would be the parallax of the Sun, if he were removed so far from us as to make the quantity of light which we should then receive from him no more than that of Saturn, or of the nearest fixed stars. Now, the distance of Saturn from the Sun is equal to about 2,082 of the Sun's semidiameters; the intensity of light, therefore, being reciprocally as the square of the distance, the density of the Sun's light at Saturn will be less than at his own surface, in the ratio of the square of 2,082, or 4,334,724 to 1. Saturn, therefore, must be less luminous than the sun in the same proportion. Again, the apparent diameter of the Sun is about 105 times greater than that of Saturn in opposition: hence, the light we receive from the former must be diminished also in the ratio of the square of 105 or 11,025 to 1. It follows, therefore, that by multiplying these two numbers together, we shall have the total light of the Sun to that of Saturn, nearly in the ratio of the square of 220,000, or 48,400,000,000 to 1.— Hence, removing the Sun to 220,000 times his present distance, he would still appear at least as bright as Saturn, and his whole parallax upon the diameter of the Earth's orbit would be less than 2'', and this, by the hypothesis, must be assumed as the parallax of the most brilliant of the fixed stars. Pursuing the same train of reasoning, this ingenious gentleman makes the annual parallax of the least fixed stars of the 6th magnitude to be from about 2''' to 3''', and their distance from about eight to twelve million times that of the Sun. Upon this supposition, the parallax of the smallest stars of the second magnitude should be about 12''',

and their distance about two million times that of the Sun.

In this computation, Saturn has been supposed to reflect all the light he receives, but this is far from being the case; and it is probable, that if we could estimate truly in what proportion that planet reflects and absorbs the light which falls upon it, we should find occasion to increase the computed distance, in a ratio which would make the annual parallax of the brightest fixed star (supposing its light not to exceed that of Saturn, and its magnitude to equal that of the Sun), considerably less than 1″.

If, however, we admit the annual parallax of the nearest fixed star, suppose Sirius, to be 1″, which is probably much too great, its distance will be no less than 20 billions of miles, a distance, through which light travelling with the immense velocity of 195,072 English miles per second, could not pass in less than three years! At what a truly inconceivable distance, then, must those minute stars be placed which can scarcely be discerned, even by the aid of the most powerful telescope, when the most brilliant star in the firmament cannot be less than 20 billions of miles from us! We shall probably be far from unreasonable, in concluding with Huygens, that there may be stars so remote, that the first beam of light which they emitted at their creation has not yet reached our Earth.

For the purpose of detecting any changes which might possibly be going on among the fixed stars, astronomers of the first eminence have at different times undertaken the very laborious task of forming catalogues of this numerous class of celestial bodies. The first catalogue upon record is that of Hipparchus, which contained 1022 stars, with

their latitudes and longitudes determined from his own observations, and those of his predecessors. To this number, four more were added by Ptolemy, since whose time other catalogues have been published by Tycho, Riccioli, Bayer, Hevelius, Flamstead, La Caille, Mayer, Bode, &c.; but the most surprising work of this kind that has hitherto appeared is the elaborate catalogue, by M. F. Lalande, in which the places of no fewer than 50,000 fixed stars, many of them of the 9th and 10th magnitudes, are accurately determined.

To these useful labours we are in a great measure indebted for the discovery of what is called the Proper Motions of the Fixed Stars, and of many other important facts, which we are now about to detail.

In speaking of the Fixed Stars, we have hitherto regarded these bodies as constantly retaining their relative positions unchanged. Dr. Halley, however, from comparing the situations of some of the Stars, as determined by ancient and modern observations, discovered that they had a motion peculiar to themselves, (generally called the proper motion of the fixed stars); and Tobias Mayer, by comparing the places of 80 stars, as determined by Roemer, with his own observations, found that most of them had a proper motion. This motion, however, is in some stars so slow, or the distance of those stars is so great, as scarcely to be perceptible, in less than half a century, while in others a small change of place may be observed every year.

Dr. Maskelyne determined by accurate observations the annual proper motion, in right ascension and declination, of a great many of the principal fixed stars. Mayer was, however, the first who ascribed the apparent change of place in the

stars to a progressive motion of the Sun and planets towards a particular quarter of the heavens, and subsequent observations have tended to verify this opinion, which is founded upon the following considerations, viz. that if the Solar system really has a motion in absolute space, directed towards any quarter of the heavens, the stars in that quarter ought to appear to recede from one another, while those which are in the opposite region would naturally seem to approach each other. Now, in most of those stars which seem to have a proper motion this motion is found to agree very well with the hypothesis, and Dr. Herschel, by comparing the proper motions of the principal stars, as determined by Dr. Maskelyne, has found that most of them are nearly such as ought to result from a motion of the Sun and his attendant planets towards λ *Herculis*, or rather towards a point in the heavens, whose right ascension is 250° 52′ 30″, and whose north polar distance is 40° 22′. Klugel found the right ascension of this point to be 260°, and Prevot makes it to be 230°, with 65° north polar distance. From his own observations upon Arcturus, Dr. Herschel infers, that the motion of the Solar System cannot be less than that of the Earth in its orbit, that it is performed round some distant centre, and that that centre is either the centre of gravity of a cluster of stars, or the common centre of gravity of several adjacent clusters. Lalande supposes that there is an equilibrium preserved among all the systems of the universe, and that they have a periodical circulation round their common centre of gravity.

In the ancient catalogues, the positions of many stars are described, of which no traces are now to be discovered, even by the aid of the most power-

ful telescopes; while, on the other hand, of several stars which now embellish the firmament no mention is made by the ancients. Some stars have suddenly made their appearance, and after continuing visible for a time, have altogether disappeared. A few stars are constantly increasing in brilliancy, while the brightness of others have been as gradually diminishing, and not a small number undergo a periodical variation of lustre.

The discovery of a new star by Hipparchus, about 120 years before Christ, gave occasion to that eminent astronomer, as we are informed by Pliny, to set about making a catalogue of the Fixed Stars, and this is the earliest observation of a new star upon record, neither are we told in what part of the heavens this phenomenon made its appearance. In the beginning of November, 1572, a new star appeared in Cassiopeia, which was observed by many astronomers, but especially by Tycho, who determined its longitude and latitude, and has given us a particular account of the phenomena it exhibited. This star when first perceived appeared in its full splendour, surpassing Venus and Mercury in brightness, and was even visible at noon day. This great splendour it retained during the whole of the month in which it was discovered; but in December its magnitude began gradually to diminish, and continued so to do till it entirely disappeared in March, 1574, after having been visible about sixteen months. The new star seen by Kepler, in the year 1604, in the east foot of Serpentarius, exhibited similar appearances, and became invisible about the end of the year following. It has not since been seen. *Deneb Kaitos*, in the tail of Citus, affords an example of those stars which are gradually increasing in lustre; as the star (δ) in the body of the Great

Bear, nearest the tail, also does of those that are constantly decreasing in brightness. Among the most remarkable of those stars, which have regular periods of variation, are *Mira*, in the neck of Cetus; Algol, in Caput Medusæ, &c.; the former of these stars varies from the 2d magnitude to a telescopic star, its period being about 334 days, and the latter, from the 2d magnitude to the 4th, with a period of 2 days, 20 hours, 48 min., 58·7 sec.

The number of stars ascertained to be variable is fifteen; but thirty-seven are supposed by Herschel to be subject to these changes, and it is probable that many more will hereafter be found to exhibit the same extraordinary appearances.

To account for these phenomena, various hypotheses have been proposed. Some have attributed them to large black spots on the surface of the stars, which being presented to us in the course of their rotation about an axis, at regular intervals, diminish the brilliancy of the star: others suppose the luminous surface of these bodies to be subject to continual changes, which sometimes increase their light, and at others diminish or extinguish it. These changes have also been ascribed to the exhaustion of the igneous matter, of which the stars are said to be composed. Some astronomers are of opinion, that the stars are extremely flat, and that they appear more or less brilliant, as their flat or sharp side is presented to us; whilst others explain the variation in the light of the stars, by ascribing it to the interposition of the planets which revolve about them.

It has been already remarked, that not more than a thousand stars are at any one time visible to the naked eye. By the aid of the telescope, however, we discover myriads of stars, which were inacces-

sible to unassisted vision; and as we increase the power of the instrument, more and more of these bodies are brought into view, so that their number, may without impropriety be considered infinite. More than two thousand stars have been observed in the constellation Orion, and above one hundred and eighty-eight in the Pleiades. Galileo found eighty in the belt of Orion's sword; twenty-one in the nebulous star in his head, and about five hundred within the space of one or two degrees, in another part of the constellation. The same observer, also, counted more than forty in Præsepe.

Dr. Herschel, however, with the aid of his most powerful telescopes, has far surpassed all others in his sidereal discoveries. In the most crowded part of that bright irregular zone, the Milky Way, that indefatigable observer has seen the surprising number of one hundred and sixteen thousand stars pass through the field of view of his telescope in one quarter of an hour's time.

Many of those stars, which to the naked eye appear single, upon the application of the telescope are resolved into two, three, four, or even many more small stars; thus, a single star in the middle of Orion's sword was found by Huygens, when examined with a powerful telescope, to consist of no less than twelve stars, very near together. Several compound stars have also been observed by Cassini, Hook, Longellas, Kelyne, and other astronomers; their number, however, has received the greatest augmentation from the labours of Dr. Herschel, who has of late years made observations upon several hundred stars of this description, most of which had not been previously noticed by any other person.

Though, perhaps, no two stars in the universe can be properly said to be altogether out of the

sphere of each other's attractions, yet many stars are obviously so remote from any other, that it would probably require some millions of years to bring them together, by their mutual action: of this description it seems are our Sun, *Arcturus*, *Capella*, *Lyra*, *Sirius*, *Canopus*, *Markab*, *Bellatrix*, *Menkar*, &c. &c. To stars, so situated, Dr. Herschel has given the name of insulated stars. Instead of supposing, as has generally been done, that every star in the heavens is a centre to an appropriate number of circumvolving planets, satellites, and comets, he imagines, that what he terms insulated stars are alone surrounded by these attendant bodies.

Under the head of double stars, or binary sidereal systems, properly so called, Dr. Herschel comprehends only such stars as when examined by the telescope are found to consist each of two stars, situated so near one another, as to be kept together by their mutual gravitation. The two bodies which compose a double star may revolve round their common centre of gravity, according to laws which have been already explained, in circles, or in similar ellipses, the dimensions of their orbit being proportional to their relative quantities of matter.

It should seem, that when two stars are so situated that the one is at an immense distance behind the other, but a little out of the line in which we see the first, they may have the appearance of a double star, though, being out of the reach of each other's attraction, they do not form a binary system. Dr. Herschel, however, is of opinion, that no two insulated stars can appear double to us; and he has shewn, that there are a great many chances against the supposition, that the multiplicity of double stars which he has discovered

should be of this description. Hence, he concludes, that their existence must be owing to their mutual gravitation; and this conclusion has received considerable confirmation, from a series of his own observations upon these phenomena, whereby he has found that double stars have actually changed their positions, with regard to one another — that the one revolves round the other, and that the motion of some of the revolving stars is direct, and of others retrograde.

The angle that a line joining the two stars forms with the direction of their daily motion, Dr. Herschel calls the *angle of position*, and from a series of observations made during a period of twenty-five years, he has found, that in upwards of fifty of the double stars, there is a change either in this angle or in the distance of the two stars. The observations that have been published, relative to the six following double stars, are too interesting to be altogether passed over in silence. The stars to which they relate, are α of the Twins, γ of the Lion, ϵ of Böotes, ζ of Hercules, δ of the Serpent, and γ of the Virgin.

Castor, the first of these, was observed by Dr. Herschel from the year 1778 to 1803. He could never detect any variation in the distance of the two stars; but from the regular decrease that he observed in their angle of position, he supposes it highly probable that the orbits in which the two stars move round their common centre of gravity are very nearly circular, and at right angles to the line in which we see them, and that the time of a whole apparent revolution of the small star round Castor will be almost three hundred and forty-two years and two months, in a retrograde direction. The distance of the two stars which form γ Leonis has undergone a sensible change,

and from the variation in the angle of position, the interval between the two stars, and the ratio of their diameters, Dr. Herschel has ascertained that the smaller one revolves round the larger in an apparent elliptical orbit, and performs an entire retrograde revolution in about twelve hundred years. The stars which compose the beautiful double star ε Böotes, differ in colour, the one being of a light red, the other of a very fine blue, and very much resemble a planet and its satellite. The orbit of the smaller star is elliptical, and it completes a revolution, according to the order of the signs, in sixteen hundred and eighty-one years. The double star ζ Herculis consists of two stars of different magnitudes; of these, the larger is of a beautiful bluish white, and the smaller of a fine ash colour. On the 11th of April, 1803, the latter suffered almost a complete occultation by the former, round which it revolves nearly in the plane of the spectator. The double star δ Serpentis has undergone a considerable change in the angle of position, without any variation in the distance between the two stars. The period of a complete revolution of the smaller star round the larger, Dr. Herschel estimates at about three hundred and seventy-five years. The two stars, of which the well-known double star γ Virginis is composed, differ but little in size. Their distance has remained the same for twenty-one years, while the angle of position has varied considerably. Dr. Herschel supposes the period of the smaller star about the larger to be about seven hundred and eight years.

The foregoing stars may be considered as affording a fair specimen of double stars, of which Dr. Herschel has given a very extensive catalogue, and has divided them into six classes. The first

class consists of those which can only be perceived under the most favourable circumstances, and by the aid of a very superior telescope. The second class contains those double stars, in which the two stars are so near each other, that their distance may be estimated by the eye, in diameters of either of them. The third class is composed of those in which the two stars are more than 5″, but less than 15″ asunder. The stars in this class may be generally seen with telescopes magnifying from 40 to 100 times.. The fourth class of double stars comprehends those whose distance asunder is from 15″ to 30″. The fifth class contains those whose distance is from 30″ to 1′; and the sixth class includes all those whose distance is from 1′ to 2′, or more.

Other stars have been pointed out by Dr. Herschel, which he supposes to be united in triple, quadruple, quintuple, and still more complicated systems.

If we examine the heavens with great attention, another class of very interesting phenomena will be discovered under the form of small luminous spots. These spots have received the name of *nebulæ*, from their nebulous or cloud-like appearance. The most interesting, and apparently the most extensive of these nebulæ, is the Galaxy or Milky Way, a well known white and luminous zone, which nearly encircles the heavens. The brightness of this zone Dr. Herschel has found, from numerous observations, made with very powerful telescopes, to arise entirely from an immense number of small stars, and he has also found that the compression of the stars increases in proportion to the brightness of the Milky Way, a portion of which, 15 degrees long and 2 broad, he found to contain no fewer than 50,000 stars, large

enough to be distinctly numbered, he also suspected that twice as many more stars were comprehended in the same space; but of these, for want of sufficient light in the telescope, he could only now and then obtain indistinct glimpses. From the very great extent of this luminous zone, the circuit it makes round the heavens, and many other circumstances which cannot be here detailed, Dr. Herschel supposes it to be a large nebula, in the inside of which the Solar System is placed, and consequently, that the Milky Way is in fact the projection of this nebula upon the concave sphere of the heavens, as seen from a point within it.

Professor Kant first suggested the idea, that all the stars in the universe are collected into nebulæ, and that all the insulated and scattered stars which appear in the heavens belong to the particular nebula in which our system is placed. This opinion was afterwards maintained by Lambert; but it is to Dr. Herschel alone that we are indebted for any thing like a confirmation of the truth of this ingenious theory. He has determined the position, magnitude, and structure of 2500 distinct nebulæ. These phenomena are presented to our view under every possible variety of shape and arrangement; some appearing double or treble; others large, with small nebulæ attached; some appear like luminous dashes of considerable extent, while others take the form of a fan, exhibiting a milky appearance; and a yet different sort are found, which shine with a mottled kind of light. Dr. Herschel generally detected these phenomena in certain directions, rather than others; and he also found that the spaces both preceding and following the nebulous strata were often so completely divested of stars, that not a single one could be perceived in the field of the telescope; from which circum-

stance he concludes, that the condensation of the stars into nebulæ has been effected by their mutual attraction. He supposes, also, that several nebulæ are formed from the decomposition of other larger nebulæ, that many of this kind have been already detached from the nebulæ of the Milky Way, and that many others are at present separating themselves from it.

Besides the nebulæ, Dr. Herschel has also discovered what he calls *nebulous stars*. These consist of single stars or bright spots, surrounded with a faint luminous atmosphere, or rather with a milky nebulosity, arising from some shining fluid. This light or fluid he has made several attempts to resolve into small stars, but without success; he therefore conceives it to be, somehow or other, formed by means of the light that is continually issuing from the innumerable suns, which occupy the immensity of space; and he supposes the bright central point to be the fluid in a condensed state; and as some of these nebulæ have no central points, he imagines that new stars may appear to be formed, by the compression of the luminous fluid.

In the foregoing remarks I have endeavoured, without entering into a minute detail of all Dr. Herschel's interesting speculations on the construction of the heavens, to give such a view of the different arrangements into which he supposes the stars to be formed, as is consistent with the popular plan of these Lectures; and shall refer those who are desirous of farther information upon this subject to Dr. Herschel's paper on the Construction of the Heavens, and the Organization of the Celestial Bodies, published in the Philosophical Transactions of 1811, which contains very interesting observations on nebulæ, and nebulous stars, and on the gradual progress of the nebulous

matter of the heavens, from its diffused state to its final condensation into perfect stars.

Among the most remarkable nebulæ which have hitherto been observed, are the following, viz.—one in Orion's sword; one in Andromeda's girdle; one near the end of the bow of Sagittarius; one between this bow and the tail of the Scorpion; one below the southern claw of the Crab; and one between the knee and left leg of Hercules.

I have now brought to a close the third and last principal division of my subject: I cannot, however, conclude these Lectures, without offering a few observations, tending to demonstrate the truth of that system of the heavens (commonly called the Copernican System) which I have been endeavouring to explain, and to shew the superiority of its pretensions over those other systems with which it is at variance, and which at different times have been more or less generally received. It will be requisite, therefore, in the first place, to give a brief sketch of those systems, and I shall accordingly begin with the

Ptolemaic System.

In this system, which is ascribed to Ptolemy of Egypt, from whom it derives its name, the Earth is conceived to be immoveable in the centre of the Universe, while the Sun, Moon, and Planets are supposed to revolve round it in the following order: viz. the Moon, Mercury, Venus, the Sun, Jupiter, Saturn. Beyond all these, the firmament of the Fixed Stars was placed in what was denominated the eighth sphere. This arrangement has obviously a reference to the time that each planet takes to complete its revolution in the heavens; and accordingly we find that the Moon is placed nearest the earth, and the Sun is made to occupy the Earth's situation, between the

orbits of Venus and Mars, and thus the respective motions of the Planets, from west to east, round the heavens, and the apparent annual motion of the Sun in the same direction, were easily accounted for. To explain the apparent diurnal motion of these bodies, the *Ptolemaics* had recourse to a ninth sphere, exterior to those already described, to which they gave the name of the *Primum Mobile*, or the first moveable; and to this they attributed a whirling motion from east to west, which communicating its influence to the inferior spheres, carried the whole, as they supposed, round the Earth in about twenty-four hours.

We have seen, however, that the planets in performing their several revolutions eastward in the heavens, appear sometimes direct, sometimes stationary, and sometimes retrograde. In order, therefore, to account for these phenomena, they supposed that each planet moved in a small circle, called an epicycle, round the centre of which it revolved much in the same way that a Satellite has been shewn to circulate about its Primary, and that the centre of this epicycle was carried round the Earth in a larger circle, to which they gave the name of *Circulus Deferens*, or the carrying circle, and by proportioning the epicycle to the deferent, a combination of motion was produced, which corresponded with the direct stationary and retrograde appearances of each particular planet. The inclination of the respective orbits of the planets to the ecliptic was easily explained, by supposing that the planes of the deferent and epicycle were inclined to that of the ecliptic. Some of these philosophers, indeed, supposed the epicycles to be solid transparent globes, to the surface of which the planets adhered, and that by these globes turning round their centre, their respective

planets being carried along with them, exhibit the direct and retrograde motions already described. They also supposed the deferents to be so many great crystalline spherical shells, inclosing each other like the coats of an onion, and that each of these shells was of a sufficient thickness to contain its respective epicyclic globe within its solid substance, and to suffer it to move freely on its own centre.

The inequality of the Sun's annual motion, and the variation in his apparent diameter, during his progress round the heavens, together with the changes in the apparent magnitudes of the planets, and the velocity of their motion, were difficulties which yet remained to be overcome. These irregularities were, however, explained, by supposing the Earth not to be concentric with the deferents, but placed at a particular distance on one side of the centre, and thus by a series of the most extravagant conjectures, aided by the most complicated and cumbrous machinery, was that celebrated system at length formed, which for upwards of 1500 years was universally received by astronomers.

In the Ptolemaic system, the Earth being supposed the common centre, round which the Sun and all the Planets revolve, it might naturally be expected, that Mercury or Venus would sometimes be found on one side of the Earth, while the Sun was on the other; that is, that Mercury and Venus would at certain times be seen in opposition; this, however, is never found to be the case; and it is even proved by the most accurate observations, that the distance of Mercury from the Sun never exceeds twenty-nine, and that of Venus forty-eight degrees. This difficulty, which proved fatal to the Ptolemaic hypothesis, gave rise to what is called

The Egyptian System,

which is in fact merely a modification of the Ptolemaic, and differs from it only in supposing Mercury and Venus, instead of revolving round the Earth like the other planets, to circulate about the Sun as their common centre, in epicycles placed upon his orbit. This new arrangement of Mercury and Venus not only removes the objection to the Ptolemaic system, but also accounts, in a very satisfactory manner, for the retrograde and stationary appearances of these planets, and may, therefore, be considered a very important improvement upon the ancient hypothesis.

The Tychonic System,

or the system introduced by Tycho Brahe, who flourished about the end of the 16th century, was distinguished from the Egyptian, by its extending the new principle of arrangement to the superior planets Mars, Jupiter, and Saturn. In the Tychonic system, therefore, the inferior and superior planets were all supposed to revolve round the Sun as a centre, while the Sun, with these attendant planets, was, nevertheless, made to revolve round the Earth, which was, therefore, still regarded as the centre of the Universe. This system must certainly be considered a very great improvement upon that of the Egyptians, as it not only explains, in a simple and satisfactory manner, the stationary and retrograde appearances, both of the inferior and superior planets, but also accounts for that remarkable increase of magnitude in the superior planets when in opposition, from the circumstance of their then being nearer the Earth. Adhering, however, to one of the grand errors of the Ptolemaic hypothesis, Tycho still supposed the apparent diurnal revolution of the Sun, Moon, Planets, and Fixed Stars, to be owing to the impression of the

primum mobile, and accounted for the immense velocity of the motion of the Fixed Stars by assuming a distance of those bodies from the Earth very far short of that beyond which it has since been demonstrated they must be placed. Longomontanus, however, one of his disciples, considerably improved his system, by ascribing to the Earth a diurnal rotation on its axis. Hence the followers of Longomontanus were denominated semi-Tychonics. It is, however, pretty evident that both the leading feature of Tycho's system, and the improvement that system received from Longomontanus, were borrowed from

The Copernican System,

which had made its appearance about 50 years anterior to that of Tycho. For this system we are indebted to the illustrious Nicholas Copernicus, a native of Thorn in Prussia, who, disgusted with the Ptolemaic doctrine of epicycles, which he regarded as inconsistent with the simplicity of nature, undertook a minute and laborious investigation of the various systems that had been invented by the ancient philosophers and astronomers, hoping among them to find some explanation of the celestial motions, more conformable to that order, harmony, and simplicity, which he conceived ought to prevail amongst these bodies.

This, however, was not his only inducement. From some remarkable coincidences which he had observed in different parts of the Ptolemaic system, he was led to suspect that the Sun was the centre round which not only the other planets but the Earth itself revolved, and he was therefore desirous of ascertaining whether a similar notion had at any time been entertained by any of those eminent philosophers who had preceded him.

Actuated by these powerful incentives, Coperni-

cus entered with avidity upon the task he had assigned himself, and his labours were crowned with complete success; for he not only found that his supposition relative to the central situation of the Sun was countenanced in a greater or less degree by many of the most celebrated philosophers among the ancients, but when he became acquainted with the system of Pythagoras, he felt convinced that he had met with the only hypothesis that gave an easy and natural solution of all the various phenomena which had hitherto perplexed the ingenuity of astronomers, so that, to use his own words, "not only the several appearances of the heavenly bodies will follow from this hypothesis, but it will also so connect the order of the planets, their orbits, magnitudes, and distances, and even the apparent motions of the Fixed Stars themselves, that it will be impossible to remove one of these bodies out of its place, without disordering the rest, and even the whole universe also."

This beautiful and harmonious system, restored by that eminent astronomer whose name it now bears, and illustrated and improved by the arduous labours and brilliant discoveries of Kepler, Galileo, Hevelius, Huygens, Cassini, Roemer, Hook, Flamstead, Newton, Halley, Bradley, Euler, La Grange, La Place, Maskelyne, Herschel, and a great number other mathematicians and astronomers, has been fully explained in the course of these Lectures, from which it appears that the peculiar tenets of the Copernican hypothesis, or those by which it is principally distinguished from the other systems that have been mentioned, are, first, the diurnal rotation of the Earth on its axis; and, secondly, its annual revolution round the Sun, supposed to occupy the centre of the planetary system. I shall, therefore, endeavour

TO DEMONSTRATE THE TRUTH OF THE COPERNICAN SYSTEM,

by proving the existence of these motions: and, first,

Of the Diurnal Motion of the Earth.

Now, the objections usually urged by the opposers of the Copernican hypothesis, against the Earth's rotation on its axis, are chiefly such as follow: viz. 1st, That if the earth turn on its axis, we who reside upon its surface ought to be sensible of this motion; in other words, that this motion ought to be perceived by us: 2dly, That this supposed rotation of the Earth on its axis, by which every point of its equator must describe a space of upwards of 1000 miles per hour, or about 500 yards per second, if it were real, would cause any body projected perpendicularly upwards from its surface, or suffered to descend freely from any considerable elevation, to fall to the west of its original position, which, however, never happens: and, 3dly, That the diurnal motion of the Earth is quite hostile to the language of Scripture. Each of these objections I shall therefore endeavour to answer in order.

And, first, that the Earth may turn on its axis without being perceived to do so, may be proved by analogy, since it is very common for a person on the surface of the Earth to be in actual and even rapid motion, when, as to sense, he appears to be perfectly quiescent. Momentary impressions of this sort must have been experienced by every one in looking out of the window of a carriage moving evenly along a road, when the trees and other objects at rest, appear to pass by the vehicle with the same rapidity with which the carriage is really moving, but in an opposite direction. This deception is perhaps more frequent and more per-

fect in the case of a person in a boat gliding smoothly along the surface of the waves, when upon casting his eyes on a vessel at rest, towards which he is approaching, he will often find it almost difficult to persuade himself that the vessel is not in motion, and himself at rest, or at least that the vessel and the boat are not mutually advancing towards each other. But the most surprising instance of this kind is met with in the case of a person in a dark night viewing the lights on shore from the cabin window of a vessel which is swinging round its anchor. Now, in this case, all intermediate objects whose state of motion or rest being known, might serve by comparison to render the deception obvious, being involved in darkness, the lights will seem to move round in regular order, while every thing on board the ship appears quite fixed and stationary. These examples are amply sufficient to prove, that a spectator in motion viewing an object at rest will perceive the same relative change of position in the object as if he were himself at rest and the object moving with an equal velocity in the opposite direction. It follows, therefore, that whether we suppose the celestial sphere to revolve round the Earth in twenty-four hours, or the Earth in that time to perform a rotation on its axis, the rising, culminating, and setting of the Sun, Moon, and Stars, with all the other celestial phenomena, will be presented in the same order, and that consequently the mere appearance of diurnal motion exhibited by the heavenly bodies affords no proof in favour of either theory, the testimony of our senses alone in this case being perfectly nugatory.

Let us, therefore, proceed to inquire which hypothesis presents the fewer difficulties, or appears to be the more plausible. We have already seen

that the distance of the Sun from the Earth is almost one hundred millions of miles. If, therefore, that luminary revolve round the Earth once in twenty-four hours, it must in that period pass over six times that space, and consequently must travel nearly at the rate of twenty-five millions of miles per hour, being more than twenty thousand times quicker than the motion of a cannon-ball! But it has been shewn, that the distance of the nearest fixed star is at least twenty billions of miles, and consequently, for that star to revolve round the Earth once in twenty-four hours, it would be requisite for it to move with the inconceivable velocity of upwards of one thousand million miles per second! a velocity far surpassing all human comprehension. Yet if, as it is reasonable to suppose, the decreasing magnitude of the stars be owing to their increasing distance from the Earth, the velocity of the daily motion of those minute telescopic stars mentioned in a former part of this Lecture, must as far exceed that of Sirius, or the nearest fixed star, as the velocity of light exceeds that of a cannon-ball.

The complication of motion which takes place among the heavenly bodies, upon the supposition that they all revolve round the Earth once in twenty-four hours, is no less surprising, than the prodigious velocity with which they move: for as the motions of these bodies must be adapted to their respective distances, in order that each of them may complete its revolution in precisely the same period of time, and as it is probable that no two stars in the firmament (to say nothing of the Sun, Moon, and Planets, whose distances we know to differ very considerably), are placed at exactly an equal distance from us, there must be as many distinct degrees of velocity, as there are individual

stars, and their number, it has already been shewn, may be considered infinite.

If now, on the other hand, we consider the apparent diurnal motion of these bodies to arise from the rotation of the Earth on its axis once in twenty-four hours, we observe the same phenomena to be produced by the most simple means, one single motion, and that comparatively moderate and easy, being alone found sufficient to accomplish that, which on the contrary hypothesis can only be affected by an infinite variety of motions, with velocities past all computation.

Again, our Earth is found to be greatly inferior in magnitude to three of the planets, viz. Jupiter, Saturn, and Uranus: while, in comparison of the Sun, it sinks into little better than a mere point; and though from being unacquainted with the real distances of the fixed stars, we are incapable of determining their true magnitude, yet it is highly probable that the size of each of these bodies is at least equal to that of our Sun. If, therefore, such be the magnitude of these vast bodies, it is surely both unnatural and unphilosophical to suppose, that a comparatively insignificant globe like our Earth stands still, while myriads of these immense bodies are perpetually circulating about it as their centre of motion.

Again, by supposing the planets to revolve from east to west round our Earth once in twenty-four hours, while we at the same time allow to each of them its proper motion in an opposite direction, we introduce such a combination or rather confusion of movements, as is totally at variance with every known principle of mechanics; whilst by imputing to the Earth a rotation from west to east on its axis, this apparent difficulty receives an easy and satisfactory solution. In addition to

which, it may be observed, that as a motion of rotation, as far as our observations have hitherto extended, seems common to all the planets, and since the earth is found to resemble them in many remarkable particulars, especially in that of being a globular body, we may consider the rotation of the Earth as a confirmation of the general analogy of the system.

But the most complete demonstration of the Earth's diurnal revolution on its axis is deduced from the particular form of the Earth itself, a full account of which has been already given in my Fifth Lecture, and need not therefore be repeated in this place.

The second objection cannot be better refuted than by the experiment of Galileo, described as follows in Derham's Astro-Theology:—"Shut yourself up," says he, "with your friend in the great cabin of a ship, together with a parcel of gnats, flies, and other little winged insects. Procure also a great tub of water, and put fishes therein. Also, hang up a bottle of water so as to empty itself drop by drop into a similar bottle with a narrow neck, placed underneath. Whilst the ship lies still, diligently observe how these little winged creatures fly with the like swiftness to every part of the cabin; how the fishes swim indifferently towards all sides; and how the descending drops all fall into the bottle beneath; and if you throw any thing to your friend, you need use no more force one way than another, provided the distances be equal; and if you leap, you will reach as far one way as the other. Having observed these particulars whilst the ship lies still, cause the ship to sail with what velocity you please, and so long as the motion is uniform, not fluctuating this way and that way, you shall not perceive any alteration in

the foresaid effects, neither can you from them conclude whether the ship move or stand still. But in leaping you shall reach as far on the floor as you did before; nor by reason of the ship's motion shall you make a longer leap towards the stern than the head, notwithstanding that whilst you were up in the air, the floor under your feet had run the contrary way to your leap. And if you cast any thing to your companion, you need use no more strength, if he should be towards the head, and you towards the stern, than if you stood in a contrary position. The drops shall all fall into the bottle that is lower, and not one towards the stern, although the ship shall have run many feet whilst each drop was in the air. The fishes in the water shall have no more trouble in swimming towards the fore part of the tub than towards the hinder part, but shall make to the bait with equal swiftness, on any side of the tub. And, lastly, the gnats and flies shall continue their flight indifferently towards all parts, and never be driven together towards the side of the cabin next the stern, as if wearied with following the swift motion of the ship. And if by burning a few grains of incense you make a little smoke, you shall perceive it to ascend on high and hang like a cloud, moving indifferently this way or that without any inclination to one side more than another."

In this experiment we have seen that the same effects are found to take place when the ship is in motion as when it was at rest, the reason of which may be thus explained. The ship and every thing on board having acquired one common motion, it is obvious that a particular motion impressed upon any one thing will have the same effect in altering its position relatively to every thing else on board, as if the ship were at rest: and that thing

will appear to act under the influence of the impressed force alone, quite independent of all other motion, whereas it is in fact acted upon by two distinct forces.

Each drop of water, therefore, in the suspended bottle above mentioned, when it begins to fall, is under the influence of two forces, namely, the motion that it has acquired in common with the ship itself, which tends to carry it forward in an horizontal direction, and the power of gravity which would precipitate it downwards in the direction of the plummet; the drop of water therefore, obeying neither or rather both of these impulses, takes an intermediate course, by which it necessarily falls into the bottle immediately beneath, whatever may be the velocity of the ship's motion at the time. Now, the same reasoning not only applies to all the other examples mentioned in the above experiment, but to the case of a stone or any heavy body let fall from the top of a tower, while the Earth revolves on its axis, in which case the stone previous to its being dropped, having acquired the same velocity with which the Earth is moving, is carried forward during the whole time of its descent, and consequently, if it meet with no obstacle to obstruct its progress, falls as exactly at the foot of the tower as if the Earth had during that time remained perfectly at rest.

As to the objection arising from the language of Scripture, this is so obviously groundless as scarcely to require refutation, since it is evident that the object of the inspired writers was to teach mankind piety and virtue, and not to instruct them in the physical sciences, or even to give an opinion respecting the celestial motions. When, therefore, they had occasion to allude to subjects of this description, either in speaking of the ordinary

appearances of nature, or in relating miraculous interruptions of such appearances, in order to render themselves universally understood, they adapted their language to the ordinary capacities, the prevailing opinions, and even in many cases to the prejudices of mankind in general, without regard to philosophic accuracy of any kind, much less to any peculiar hypothesis of the heavenly motions. Thus, when in Joshua the Sun is ordered to stand still upon Mount Gibeon, and the Moon in the valley of Ajalon — where also in Isaiah, the Sun is said to have gone backwards — and again in the Psalms, when it is spoken of as going forth from the end of the heavens, and hastening to it again — it is obvious to the most uninformed, that in all these instances things are spoken of rather as they appeared than as they really were; and we have no more reason to find fault with this mode of expression, than with our calling the Moon new every time it comes into conjunction with the Sun, when we are, notwithstanding, fully aware that it is the same Moon which has attended our earth ever since its first creation.

Having thus replied at considerable length to the most important objections against the Earth's diurnal rotation, let us in the next place inquire what evidence can be obtained

Of the Earth's Annual Motion.

An easy method of tracing the apparent path of the Sun through the heavens has been given in a former Lecture,[1] in a subsequent part of which this path, commonly called the ecliptic, and apparently described by the Sun, has been considered upon the Copernican hypothesis, to be really described by the Earth in its annual revolution round

[1] See Lecture VIII. pp. 129, 130.

that luminary. In either case, however, it is obvious, that, whatever point of the heavens the Earth appears to be in as seen from the Sun, the Sun must appear to be in the opposite point of the heavens as seen from the Earth. It has also been shewn upon the same hypothesis, that the vicissitudes of the seasons, or the regular increase and decrease which take place in the length of the days and nights, are produced by the Earth's axis being inclined 66½ degrees to its orbit, and kept constantly parallel to itself in every point of its revolution. On the other hand, however, it must be acknowledged, that the same effects would also result from the Sun's orbit being inclined 23½ degrees to the equinoctial. Here, therefore, as in the case of the Earth's diurnal motion, appearances alone are perfectly indecisive in favour of either theory. More substantial proofs of the Earth's annual motion are, however, fortunately by no means difficult to be met with, and I shall therefore produce a few, which, being principally derived from subjects already fully explained in the course of these Lectures, will be comprised in a few words.

The apparently complicated motions of the planets, we have found can only be satisfactorily accounted for, by supposing them to revolve about the Sun as their common centre. It has also been proved by the motion of spots on their surface, that all of them have a rotation on their axis. Since, therefore, the Earth has been demonstrated to resemble them in the latter particular, and is besides an opaque body poised in space, we are led by analogy to conclude, that this Globe has in like manner an annual motion round the Sun; and since it has been found that Mercury and Venus are never seen in opposition, but are occasionally in inferior or superior conjunction, while the other

planets are sometimes in superior conjunction with the Sun, and sometimes in opposition to that luminary, but are never in inferior conjunction with him; it is obvious, that if the Earth revolve round the Sun, its orbit must be exterior to the orbits of Mercury and Venus, and interior to those of the rest of the planets: in other words, it must be situated between the orbits of Venus and Mars. By this arrangement, therefore, the harmony of the system is established, while, upon the contrary hypothesis, the whole planetary system becomes completely deranged.

But again, every body revolving round another body is retained in its orbit by the power of gravity or attraction, which power is always proportional to the quantity of matter in bodies. It is obvious, therefore, that a comparatively diminutive body like our Earth must be utterly incapable of exerting a restraining influence upon the Sun, whose gravity so vastly exceeds its own. Yet the absurdity of the Ptolemaic and Tychonic systems does not stop here; for, according to either of these hypotheses, the Earth is not the centre of the Sun's motion only, but of the motion of the planets likewise, and consequently must by its gravity retain all these bodies in their respective orbits.

Many other inconsistencies necessarily arise from supposing the Earth to occupy the centre of the planetary system; they are, however, for the most part, too obvious to require any particular notice. I shall, therefore, in the last place, observe, that while on the one hand the most formidable objection which could be urged against this motion has been satisfactorily refuted, by proving (as we have done in the preceding part of this Lecture) that the Earth's orbit, compared with the distance of the nearest fixed star, is but a mere dimen-

sionless point; on the other hand, a direct demonstration of the existence of this motion is found in the aberration of light, a phenomenon which, as we have already shewn, arises from a combination of the motion of light with the annual motion of the Earth in its orbit. The Copernican system is in fact the only one which, together with the Newtonian doctrine of universal gravitation, already explained, accounts in a satisfactory manner for the various irregularities observable in the motions of the celestial bodies.

I shall now, therefore, having established the two grand principles upon which this system rests — namely, the Earth's diurnal rotation on its axis, and its annual revolution in its orbit — conclude my twentieth and last Lecture.

APPENDIX.

Many of the Greek characters having been employed in the fourth Lecture as references to the dark portions of the lunar disc, it will be proper, in order to render them understood by those who may chance to be unacquainted with those characters, to introduce in this place

THE GREEK ALPHABET.

		NAME.	SOUND.
Α	α	Alpha	a
Β	β ϐ	Beta	b
Γ	γ ϒ	Gamma	g
Δ	δ	Delta	d
Ε	ε	Epsilon	e *short.*
Ζ	ζ ϛ	Zeta	z
Η	η	Eta	e *long.*
Θ	ϑ θ	Theta	th
Ι	ι	Iota	i
Κ	κ	Kappa	k
Λ	λ	Lamda	l
Μ	μ	Mu	m
Ν	ν	Nu	n
Ξ	ξ	Xi	x
Ο	ο	Omicron	o *short.*
Π	π ϖ	Pi	p
Ρ	ϱ ρ	Rho	r
Σ	ϲ σ ς	Sigma	s
Τ	τ 𐅃	Tau	t
Υ	υ	Upsilon	u
Φ	φ	Phi	ph
Χ	χ	Chi	ch
Ψ	ψ	Psi	ps
Ω	ω	Omega	o *long.*

QUESTIONS AND EXERCISES

ADAPTED TO THE

PRECEDING LECTURES.

QUESTIONS AND EXERCISES ON LECTURE I.

1. Of what does the science of astronomy treat?
2. Under the general term heavenly bodies, what bodies are comprehended?
3. Which of these bodies appear to have a proper motion of their own?
4. How are comets distinguished from planets?
5. Of what bodies does the planetary system consist?
6. What is a primary planet?
7. Name the primary planets, and draw their characters.
8. How are the minor primary planets distinguished from the primary planets?
9. Name the minor primary planets, and make their characters.
10. Explain the meaning of the terms superior and inferior, as applied to the planets.
11. Which of the planets are superior, and which inferior, with regard to our earth?
12. What is a secondary planet, satellite, or moon?
13. Which of the planets have satellites?
14. How many bodies compose the planetary system?
15. What do you understand by the orbit of a planet?
16. Of what figure is it?

17. Describe from fig. 1. the various parts of an elliptic orbit.
18. Explain the meaning of the terms aphelion, perihelion, apogee, and perigee.
19. Does the line of the apsides of every planet lie in the same direction?
20. What is the ecliptic, and why is it so denominated?
21. What is meant by the heliocentric circle of a planet?
22. What are the nodes of a planet?
23. How is the apparent annual revolution of the Sun produced?
24. Into how many equal parts is the ecliptic divided?
25. How far does the zodiac extend on each side of the ecliptic, and why is it called the zodiac?
26. Name the signs of the zodiac.
27. Sketch out the characters by which the signs are represented, and explain their signification.
28. Do the signs of the zodiac correspond with the constellations after which they are named?
29. Distinguish the astral from the fixed or local zodiac.
30. By whom, and when, was the fixed zodiac first introduced among the Greeks?
31. Did the signs of the zodiac in the time of Hipparchus correspond with the constellations after which they are named?
32. To what cause is the change which has since taken place in the situation of the signs to be attributed?
33. At what angles are the orbits of the planets severally inclined to the ecliptic?
34. In what direction do the planets revolve on their axes?
35. What is meant by the axis of a planet or other heavenly body?
36. What are the extreme points of the axis called?
37. What is that circle called which divides the Earth into two equal parts, and to the plane of which the Earth's axis is perpendicular?
38. What are those two parts called into which the Earth is divided by this circle?

39. In fig. 2. point out the angle of inclination of the Earth's axis to the ecliptic; also, the obliquity of the ecliptic to the equator.
40. What are those points called in which the equator intersects the ecliptic, and why are they so called?
41. From what is their name derived?
42. What is the latitude of a heavenly body?
43. Had the Earth's axis been perpendicular to the plane of its orbit, what coincidences would have taken place?
44. What are those points in the celestial sphere called, through which the Earth's axis infinitely extended both ways would pass?
45. On what circle is the longitude of a heavenly body measured?
46. At what point in that circle does the reckoning commence?
47. How is it counted?
48. Describe the difference between the heliocentric and geocentric latitude and longitude of a heavenly phenomenon.
49. What do you understand by the right ascension of a celestial body?
50. What is its nearest distance from the equinoctial called?

QUESTIONS AND EXERCISES ON LECTURE II.

51. What was the common Greek name of the Sun?
52. What is its Latin name, and how is it accounted for by Macrobius?
53. What is the diameter of the Sun?
54. What did the ancients suppose the Sun to be?
55. What appearances were detected on the disc of the Sun by the aid of the telescope?
56. In what direction do the spots on the Sun appear to move?
57. Describe the general appearance of a spot in its progress across the disc of the Sun.

58. In what part of its passage does it appear to move fastest?
59. What were the dark and bright spots observed on the Sun's disc formerly called?
60. When several spots appear at the same time upon the surface of the Sun, do they all preserve the same position relatively to one another during the whole time of their being visible?
61. Is the apparent path of a spot over the Sun's disc the same at all times of the year?
62. Describe the varieties it undergoes.
63. To what may the apparent motion of the solar spots be attributed, and what do astronomers obtain a knowledge of by tracing their progress over the Sun's disc?
64. What is the inclination of the Sun's axis to the plane of the ecliptic?
65. How may the true time of the Sun's rotation on his axis be ascertained?
66. Who is generally supposed to have been the first observer of the solar spots?
67. Describe the general appearance of a solar spot.
68. What is remarkable in the outline of the umbra that generally surrounds the nucleus of a spot?
69. Are the spots on the Sun found to be permanent?
70. When a spot disappears does the umbra or the nucleus first become invisible?
71. By what is the umbra generally succeeded?
72. How did Scheiner account for the phenomena called solar spots?
73. What other opinions have been entertained concerning them?
74. What inference did Dr. Wilson draw from his observations of these phenomena?
75. Upon what peculiar appearances exhibited by these spots, did Dr. Wilson found his solar theory?
76. Of what does Dr. Herschel suppose the lucid matter of the Sun to consist?
77. What does he suppose the nucleus of the spot to be?

78. What names did Dr. Herschel give to those phenomena formerly denominated nuclei, umbræ, feculæ, luculi, &c.?
79. What are openings?
80. How does Dr. Herschel account for their production?
81. What are shallows?
82. Describe the various appearances they sometimes exhibit.
83. What are ridges, and how far have they been observed to extend?
84. What are nodules, and what does Dr. Herschel conjecture from their never appearing near the centre of the Sun's disc?
85. What are corrugations?
86. What are indentations?
87. What are pores?
88. Of what does Dr. Herschel suppose the Sun to consist?
89. What is Dr. Brewster's opinion concerning the probable construction of this great luminary?
90. At what part of the Sun's disc is his light found to be most intense?
91. To what cause is the zodiacal light generally attributed?
92. What other name has this phenomenon?
93. What form does it assume?
94. How is its lenticular figure supposed to be produced?
95. By whom was this phenomenon first particularly noticed?
96. What was his first opinion respecting it?
97. Did he long retain this opinion?
98. How did he afterwards suppose it to be caused?
99. Draw the character by which astronomers denote the Sun.
100. What is it supposed to represent?

QUESTIONS AND EXERCISES ON LECTURE III.

101. Which is the nearest planet to the Sun?

102. On what account did the Romans name him Mercurius?
103. What is his mean hourly motion in his orbit?
104. What does the character astronomers employ to denote this planet represent?
105. What is the diameter of Mercury?
106. In what time does it revolve round the Sun?
107. What is its mean distance from that luminary in round numbers of miles?
108. What appearances does it exhibit when examined with a powerful telescope?
109. What is the length of its day?
110. What was the height of a mountain in the southern hemisphere of Mercury, the altitude of which was measured by Schroeter?
111. Which is the next planet in the system to Mercury?
112. What was Venus called by the Greeks when she rose before the Sun in the morning, and what when she set after him in the evening?
113. How was she denominated by the Romans under similar circumstances?
114. What does her astronomical character represent?
115. What is the diameter of Venus?
116. How long does she take to move once round the Sun?
117. What is her distance from the Sun?
118. Has she different phases?
119. What two great observers of Venus disagreed materially with regard to the time of her rotation on her axis?
120. Whose opinion was afterwards confirmed by Schroeter, and what is the true time of her rotation or the length of her day?
121. What planet revolves round the Sun between the orbits of Venus and Mars?
122. What is the astronomical character of Mars?
123. What is the diameter of Mars; what the period of its revolution round the Sun; and what its distance from that luminary?

124. Mars shines with a very red light; explain the cause of this phenomenon.
125. What peculiar appearances have been observed about the polar regions of Mars?
126. How long does Mars take to complete a revolution on his axis, according to Dr. Herschel?
127. Which is the next planet in the system to Mars?
128. What is the character by which astronomers represent Jupiter?
129. What is his diameter and his distance from the Sun?
130. In what time does Jupiter revolve on his axis?
131. How long is Jupiter revolving once round the Sun?
132. Describe the telescopic appearance of this planet.
133. Are all the spots observed on Jupiter supposed to be permanent?
134. To what may be attributed the difference of colour in Jupiter's belts, and the changes that are continually taking place in them?
135. Which was the most remote planet known to the ancient astronomers?
136. By what names was this planet known among the Greeks?
137. What is Saturn's astronomical character?
138. What is his diameter?
139. In what time does Saturn revolve round the Sun?
140. What is his distance from the Sun?
141. By what singular appendage is Saturn distinguished from all the other planets?
142. Who first observed an uncommon appearance in this planet?
143. Who first ascertained that Saturn was encircled by a ring?
144. Describe the telescopic appearances of this ring, with Dr. Herschel's opinion of its matter and form.
145. How many times does the outer diameter of the exterior ring of Saturn exceed the diameter of the Earth?

146. In what respect does the surface of Saturn resemble that of Jupiter?
147. Saturn and his ring revolve round the same axis; is their period of rotation the same, or if not, which exceeds the other, and how much?
148. What different names is the next planet to Saturn, in the system, known by, and what is its astronomical character?
149. What is the diameter of Uranus, its distance from the Sun, and its period of revolution round that luminary?
150. Is the time of its rotation on its axis ascertained?
151. What induced astronomers, before the discovery of the minor primary planets, to suppose that a planet revolved round the Sun in the interval between the orbits of Mars and Jupiter?
152. How was this opinion afterwards realized?
153. Why may the four newly discovered planets be considered minor primary planets?
154. What did Dr. Herschel call them?
155. By what names are they individually distinguished?
156. Where, when, and by whom was Ceres first discovered?
157. Which of these bodies was next discovered, and by whom?
158. When and where was this discovery made?
159. When was Juno first observed?
160. Who had the honour of discovering it?
161. By whom was Vesta first observed, and when?
162. In what time does Vesta revolve round the Sun, and what is her mean distance from him?
163. What is the mean distance of Juno from the Sun, and how long does she take to revolve round him?
164. What is the period of Ceres's revolution in her orbit, and what is her mean distance from the central luminary?
165. How long is Pallas circulating once round the Sun, and what is her mean distance from him?

166. What does the astronomical character of each of these minor primary planets represent?
167. What did Dr. Olbers suppose these planets to be?
168. Which of them is sometimes visible to the naked eye?
169. Has the time of their rotation on their axes been ascertained?

QUESTIONS AND EXERCISES ON LECTURE IV.

170. What body constantly attends our Earth in its revolution round the Sun?
171. What is the astronomical character of the Moon?
172. What is her real diameter?
173. Being so much smaller than any of the planets, what causes her to appear so much larger?
174. A very curious appearance is exhibited by the Moon when about three or four days old; what is the phenomenon vulgarly called?
175. Describe the phenomenon itself.
176. How has it been supposed to be produced?
177. How do philosophers endeavour to account for the faint light that is spread over the surface of the old Moon, at the time of the phenomenon above-mentioned taking place?
178. How does Dr. Brewster suppose the lucid bow on the eastern limb of the old Moon to be formed?
179. What is the general appearance of the lunar disc, when examined with a powerful telescope?
180. Give a more particular description of the lunar spots, and of the varieties they undergo during the increase and decrease of the Moon.
181. What may be naturally inferred from these appearances?
182. What is supposed to be the height of some of the lunar mountains?
183. What are the dark portions of the lunar disc generally supposed to be?
184. Who first suggested the idea of there being volcanoes in the Moon?

185. What eminent astronomer witnessed several appearances of this kind, and has given us a particular account of his observations upon them?
186. To whom are we indebted for the complete discovery of a lunar atmosphere?
187. What is the utmost height at which it is dense enough to inflect the rays of the sun, or to affect the brightness of a fixed star?
188. How have the various appearances of the lunar disc been represented?
189. Who first made a map of the Moon?
190. How did he denote the various spots on her surface?
191. How did Hevelius distinguish them?
192. Find the Crisian Sea on the map of the full Moon, fig. 11.
193. What is the name of the spot marked β?
194. Which spot is denominated the Lake of Death?
195. How does the Sea of Vapours lie from the Sea of Serenity?
196. What is the spot marked ι called?
197. Is the Lake of Sleep or the Crisian Sea the more easterly?
198. Which is the most extensive spot on the lunar disc?
199. Describe the situation of the Bay of Rainbows.
200. Where is the spot Tycho, and for what is it remarkable?
201. Which is the brightest part of the full Moon, and how is this brilliant spot situated?
202. By whom and when were the satellites of Jupiter discovered?
203. What is their number, and in what order are they reckoned?
204. In what time does each of these bodies revolve round Jupiter?
205. Do they always appear in the order of their respective distances from him?
206. What time do these satellites take to revolve on their axes?
207. How many satellites has Saturn?

208. By whom were the sixth and seventh satellites discovered?
209. In what order do these bodies revolve round Saturn?
210. Are the orbits of all the satellites equally inclined to the plane of Saturn's orbit?
211. What happens to the fifth satellite when it arrives at its greatest eastern elongation or distance from Saturn?
212. What is the distance of the sixth or nearest satellite from Saturn, and in what period does it revolve round its primary?
213. How far is the seventh satellite from Saturn, and how long does it take to go once round him?
214. In what time does the first satellite revolve round Saturn, and at what distance from him?
215. How long does Saturn's second satellite take to move once round its primary, and how far is it from Saturn?
216. How much does the distance of the fourth satellite of Saturn exceed that of the third, and how much longer is it revolving round him?
217. How much does the period of the fifth satellite exceed that of the seventh, and how many miles is the latter nearer to Jupiter than the former?
218. Which of Saturn's satellites is the largest?
219. How many satellites has Uranus, and by whom were they discovered?
220. What is remarkable in the direction of their motion round their primary?
221. In what time do they severally revolve round Uranus, and what is the distance of each from him?

QUESTIONS AND EXERCISES ON LECTURE V.

222. What was the opinion of Heraclitus respecting the form of the Earth?
223. What other forms were ascribed to it before it was found to be globular?

224. What people are said by Diogenes Laertius, not only to have known the earth to be spherical or nearly so, but also to have been acquainted with the cause of lunar eclipses?

225. How may the convexity of the surface both of the sea and land be ascertained?

226. What affords the most satisfactory proof of the sphericity of the Earth?

227. After the convexity of the Earth's surface had been completely ascertained, what did astronomers suppose to be the Earth's true figure?

228. Into how many varieties may gravity be distinguished?

229. What is meant by particular or terrestrial gravity?

230. What is general or universal gravity?

231. Why does a stone dropped from the top of a tower — or any other body left unsupported — descend to the Earth in a right line perpendicular to its surface?

232. Has the Earth an upper or under side?

233. How does gravity affect all falling bodies, and what is it that causes some bodies to descend with greater rapidity than others?

234. Describe the law by which gravitation acts.

235. Why is it that in all experiments made upon the weight of bodies, gravity assumes simply the form of a constantly accelerating force, without exhibiting any change in its effects agreeable to the law already described?

236. If we consider gravity as a constant force, what rule shall we have for the descent of circumterrestrial bodies?

237. How may we account for the descent of a projectile in a curved line?

238. What is the difference between the gravity and the weight of a body?

239. Richer found that the pendulum of his clock, which at Paris vibrated true seconds, lost two minutes and twenty-eight seconds per day in the

island of Cayenne, near the equator: and that in order to make it vibrate true seconds, it was necessary to shorten it about the eleventh part of an inch — to what great discovery did this observation pave the way?

240. Explain upon what principles it might naturally be inferred from the above circumstance, that Cayenne was farther from the centre of the Earth than Paris, and consequently that the distance of the equator from that centre must exceed that of any other part of the Earth's surface; and that the Earth, therefore, is not a true sphere, but an oblate spheroid, compressed at the polar and swelled out at the equatorial regions.

241. What is the probable difference between the polar and equatorial diameters of the Earth?

242. What is the cause of the Earth's assuming a spheroidal form?

243. How does the Earth's rotation on its axis produce this effect?

244. With what degree of velocity would it be necessary for the Earth to revolve on its axis, in order that all bodies without losing their situation on the Earth's surface, might become entirely destitute of weight.

QUESTIONS AND EXERCISES ON LECTURE VI.

245. The Earth is surrounded on every side by a fluid mass, which extends to a considerable height above its surface, what is this fluid mass called?

246 Of what is the atmosphere composed?

247. Is it endued with weight?

248. What is the weight of the atmosphere on every square inch of the Earth's surface?

249. By what means is the weight of the atmosphere ascertained?

250. What is the weight of the whole atmosphere?

251. What would be the diameter of a globe of lead

equal in weight to the whole atmosphere, according to Mr. Cotes?

252. Estimating the surface of a middle-sized man at 14 square feet, what pressure of atmosphere does he sustain?

253. How is it that we are insensible of the external pressure of the atmosphere?

254. What mistake is frequently made with respect to the cause of a languid sensation with which we are apt to be affected in bad weather?

255. Which parts of the atmosphere are most dense?

256. What causes the clouds to float in the atmosphere, and why do they not ascend to indefinite heights?

257. At what height above the Earth's surface, would a cubic inch of the air we breathe be so much rarified, as to fill a sphere equal in diameter to the orbit of Saturn?

258. Of what does light consist?

259. What is a ray of light?

260. What is meant by a pencil of rays?

261. What is a beam of light?

262. What proportion does the number of grains of light emitted by a burning candle in one second of time, bear to the number of grains of sand contained in the whole Earth, supposing every cubic inch of the Earth to contain one million of such grains?

263. What is the ordinary rate at which a cannon-ball moves per hour?

264. How long would it be in going from the Earth to the Sun, if it were to continue to move with the same velocity with which it was first projected?

265. How long is a ray of light passing from the Sun to the Earth, and what is the velocity of its motion?

266. In what proportion does the velocity of light exceed that of a cannon-ball?

267. In what proportion is the force with which moving bodies strike, and what effect would take

place if 1,463,094 grains of light were equal to a single grain of sand?

268. What is an opaque body?

269. How does an opaque body shine?

270. In what direction does light when emitted or reflected always move?

271. What is a medium?

272. Why is light subject to the power of attraction which in certain cases overcomes its tendency to move in a right line?

273. Under what peculiar circumstances is this effect produced?

274. How is a ray of light said to be affected when it is drawn out of its natural course?

275. What is the angle of incidence?

276. What is the angle of refraction?

277. How is a ray of light affected in passing from a more rare to a denser medium?

278. How is it affected in passing from a dense medium to one of greater rarity?

279. How may these laws of refraction be experimentally illustrated?

280. Does any change take place in the direction of a ray of light striking the surface of the refracting medium perpendicularly?

281. What is the refraction in proportion to?

282. What is the greatest height at which the atmosphere is dense enough to refract the rays of light?

283. Show by fig. 12. that refraction tends to increase the apparent altitude of a heavenly body.

284. In what situation is a heavenly body most affected by refraction, and why?

285. Does the refraction increase or decrease with the altitude of the celestial body?

286. In what point must the body be situated for the refraction to be nothing, and why?

287. What is the angle of refraction?

288. What very curious phenomenon has been known to result from the horizontal refraction?

289. What causes the Sun and Moon to assume an oval form at rising and setting?
290. What effect is produced by the reflective power of the atmosphere?
291. About how many degrees is the Sun below the eastern verge of the horizon when the morning twilight begins?
292. When does the evening twilight end?
293. Is the twilight of an equal duration in all latitudes, and at all times of the year?
294. When is it found to be the shortest in our latitudes?
295. What does the term meteor comprehend?
296. What causes that beautiful phenomenon called the iris or rainbow?
297. Why does it always assume a semicircular appearance?
298. How must the spectator be situated relatively to the Sun and the shower that the rainbow may be visible, and what is the least altitude of the Sun necessary for producing this phenomenon?
299. Describe the phenomenon called the halo or corona.
300. What are parhelia, and by what are they caused?
301. By what are they generally attended?
302. What are paraselenæ?
303. How are falling or shooting stars produced, and of what do they consist?
304. What opinion did the ancients entertain with respect to the meteors called fire-balls?
305. Where are they most common, and what is their general appearance?
306. Describe the remarkable one seen in this country in the year 1783.
307. What circumstances generally attend the disappearance of these phenomena?
308. Of what are meteoric stones composed?
309. What is the opinion of Dr. Chladni respecting these meteors?
310. Whence does La Place suppose meteoric stones to be projected?

311. What is the most general opinion respecting the origin of these bodies?
312. What is the meteor called ignis fatuus, or wandering fire, supposed to be?
313. What description does Dr. Shaw give of one seen by him in the Holy Land?
314. How does Sir Isaac Newton define the ignis fatuus?
315. In what part of the heavens does the aurora borealis make its appearance?
316. Where are the northern lights seen with the greatest effect?
317. Describe the appearances they exhibit.
318. To what is the aurora borealis probably owing?
319. What is dew?
320. How is snow formed?
321. How is thunder produced, and what is lightning?
322. Where are water spouts most common?
323. Describe the method in which they are produced.

QUESTIONS AND EXERCISES ON LECTURE VII.

324. What is the horizon?
325. Distinguish the sensible from the rational horizon.
326. What are the poles of the horizon called?
327. What is the zenith?
328. What is the nadir?
329. What are almacanters?
330. Why are they sometimes denominated parallels of altitude?
331. What are vertical circles?
332. What is that vertical called which passes through the north and south points of the horizon?
333. What is that called which passes through the east and west points?
334. What are great circles passing through the poles of other great circles commonly called?

335. What is the semi-diurnal arch of any heavenly body?
336. What is the amplitude of any heavenly body?
337. What is its azimuth?
338. Why are vertical circles sometimes called azimuth circles or azimuths?
339. How far distant are the poles of the ecliptic from those of the equator respectively?
340. What is the solsticial colure?
341. What is the equinoctial colure?
342. Does the apparent diurnal revolution of the heavenly bodies appear under the same circumstances, as viewed from all parts of the Earth's surface?
343. How do the heavenly bodies appear to rise and set to an inhabitant of the equator?
344. Why is a spectator so situated, said to have a right position of the sphere?
345. Why will his days and nights be of an equal length throughout the whole year?
346. How much of the starry sphere will appear to him to rise and set every twenty-four hours?
347. What great circle of the sphere becomes his prime vertical?
348. To an inhabitant at either of the poles, what great circle of the sphere coincides with his horizon; and what points has he in his zenith and nadir?
349. To an observer so situated, how will the Sun, Moon, stars, &c. appear to move?
350. What position of the sphere is he said to have?
351. Will all the stars pass through his visible hemisphere?
352. What will be the length of his day and night?
353. What position of the sphere is an observer between either of the poles and the equator said to have, and why?
354. What is the largest circle in the sphere of the heavens, parallel to the celestial equator, which appears entire above the horizon of any place, called?
355. What is the largest parallel in the celestial sphere,

which never rises above the horizon of any place, called?

356. What are the stars called which are comprehended within these circles?

357. How far are the circles of perpetual apparition and occultation of any place from their respective poles?

358. What stars never set to the inhabitants of London?

359. Does the magnitude of the circles of perpetual apparition and occultation increase or diminish with the distance of the place from the equator?

360. To those who inhabit the poles or have a parallel position of the sphere, what great circle becomes both the circle of perpetual apparition and occultation?

361. Have the inhabitants of the equator any circle of apparition or occultation?

362. To what body have the poetical risings and settings of the stars a reference?

363. Of how many kinds are they?

364. What are they called?

365. When is a star said to rise or set cosmically?

366. When is a star said to rise or set acronycally?

367. What is meant by the heliacal rising or setting of a star or planet?

368. From what did the ancients reckon the commencement of the dog-days?

369. Show that what are termed the dog-days have now (at least in our latitude) no connection with the heliacal rising of Sirius.

370. On what day did the Sothic year of the Egyptians begin?

371. Why did they commence their year at that time?

372. Why was the dog-star called Sirius?

373. What is supposed to have suggested the idea of representing the constellation to which this beautiful star belongs, under the figure of a dog?

QUESTIONS AND EXERCISES ON LECTURE VIII.

374. What is the time at any place, when by the diurnal rotation of the Earth on its axis it is brought immediately under the Sun? and how is the Sun said to be situated with regard to that place?
375. What is a natural day?
376. How is the natural day divided?
377. The equator being divided into 360 equal parts called degrees, and the Earth revolving on its axis in 24 hours, how many degrees of the equator revolve in or correspond to one hour of time?
378. What are the hour circles of any particular place?
379. Explain the general phenomena of the Earth's diurnal rotation, by means of diagram 2.
380. What persons have their time earlier than the inhabitants of any particular place?
381. If when it is nine o'clock in the morning at one place, it is found to be twelve o'clock at noon at another, how is the latter place situated with regard to the former?
382. Will a person setting out from any place, and travelling eastward round the Earth, have gained or lost a day in his reckoning when he returns to that place again, and why?
383. Suppose a person to set out exactly at midnight, and to travel due east at the rate of 15° in an hour, how long will it be before he has the Sun on his meridian?
384. If instead of due east he travels due west at the same rate, and set out at the same hour (viz. at midnight), when will he have the Sun on his meridian?
385. In what manner may the Sun's annual progress round the heavens be detected?
386. Does the Sun always rise due east and set due west?
387. On what days does it do so?
388. How long together does the Sun continue to rise

north of the eastern point of the horizon, and set north of the western?

389. How long together does he continue to rise and set south of those points?

390. On what day of the year does he rise and set most northerly?

391. On what day does he rise and set most southerly?

392. What does this change in the rising and setting points of the Sun throughout the year, prove?

393. By what other method may it be demonstrated that the Sun's apparent annual motion is not performed in the equinoctial — in other words, that the Sun has north declination during one half of the year, and south during the other?

394. On what day of the year will the Sun's meridian altitude be greatest, and on what day will it be least?

395. What is the difference between the greatest and least meridian altitudes of the Sun?

396. What, therefore, is the obliquity of the ecliptic?

397. Does any change take place in the obliquity of the ecliptic?

398. What is its annual diminution?

399. Describe the method by which the Sun's apparent annual path through the heavens (commonly called the ecliptic) may be traced among the stars.

400. What are those parallels called which the Sun describes when at its greatest distance from the equinoctial, and why are they so called?

401. What is that tropic called which is north of the equinoctial, and why is it so named?

402. Why is that tropic which is south of the equinoctial called the tropic of Capricorn?

403. Why are these points called the solsticial points or solstices?

404. To the inhabitants of what portion of the Earth's surface, do the terms Spring, Summer, Autumn, and Winter, as applied to the equinoxes and solstices, relate?

405. What is that circle parallel to the equinoctial, called, whose distance from the north pole is 23° 28′?
406. What is that parallel denominated, whose distance from the south pole is the same?
407. Explain the meaning of these terms.
408. With what does the variation in the meridian altitude of the Sun correspond?
409. In order to produce these varieties, what must be the position of the Earth's axis relatively to the plane of its orbit?
410. On what days of the year does the Sun rise at six o'clock in the morning, and set at six in the evening?
411. On what day does the Sun remain something more than sixteen hours above the horizon of London without setting?
412. On what day does the time of his continuance above our horizon not exceed eight hours?
413. Explain the situation of the Earth with regard to the Sun on the days of the equinoxes and solstices, by means of fig. 13.
414. Give a more complete illustration of the regular increase and decrease which take place in the length of day and night throughout the year, and of the whole theory of the seasons, by means of diagram 3.
415. Show by the circle of hours attached to the Earth in this diagram, at what time the Sun rises and sets on the first day of every month throughout the year.
416. Mention the days on which he enters the several signs of the ecliptic.
417. Name the signs belonging to each season of the year.
418. Why is so little heat derived from the Sun in Winter?
419. What causes conspire to produce the heat of Summer?
420. It is found by experience that we have not the hottest weather at Midsummer, when these

causes operate most forcibly, but generally about a month after the Sun has left the tropic of Cancer — neither have we the coldest weather when he is in the Winter solstice, but about the latter end of January or the beginning of February, when he has made some considerable progress in his return towards the equinoctial — account for these apparent inconsistencies.

421. Which are denominated northern signs — and which southern?

422. Which are called ascending and which descending signs?

QUESTIONS AND EXERCISES ON LECTURE IX.

423. How do the equinoxes divide the year?

424. How much longer is the Sun in going from the vernal equinox to the autumnal, than he is in passing from the autumnal to the vernal?

425. From this circumstance what may naturally be inferred with regard to the apparent motion of the Sun?

426. Is the apparent motion of the Sun actually found by observation to be subject to inequalities?

427. At what time of the year is the Sun's apparent motion the fastest?

428. When is it slowest?

429. Is the apparent diameter of the Sun constantly the same?

430. With what does the change which takes place in his apparent diameter correspond?

431. How may the coincidence between his apparent diameter and the velocity of his motion, be proved?

432. What causes the apparent diameter of the Sun to be continually varying?

433. The apparent annual motion of the sun being caused by the Earth's motion in its orbit, and these changes in his apparent diameter being regularly repeated every year, what do they prove?

434. All the planets in the system, whether primary or secondary, revolve round their respective centres in ellipses, they are all subject to a similar inequality of motion; and in performing their several revolutions they all observe one general law; what is that law?
435. Illustrate by diagram 4. the motion of a planet in an elliptic orbit?
436. Do the orbits of the planets differ much from true circles?
437. Is the Earth nearer the Sun in Winter or in Summer?
438. Why have we not the warmest weather, when the Earth is nearest the Sun?
439. Who first discovered that the planetary orbits were of an elliptical figure, and the law according to which they revolve in their respective orbits?
440. What other remarkable fact did he discover relating to these bodies?
441. What were these important discoveries of Kepler afterwards denominated?
442. How are they usually expressed?
443. By whom have they been since demonstrated, and upon what principles?
444. If a body gravitating towards a centre receive a projectile force in a direction not passing through that centre, what line will it describe by its compound motion; and what tendency will it have while describing this line?
445. What is the centrifugal force?
446. What is the centripetal?
447. What are these two forces by the joint action of which the planets are retained in their orbits, called?
448. Explain by fig. 16. in what manner these two forces affect the motion of a planet, causing the radius vector to pass over equal areas in equal times.
449. Under what circumstances would the joint action

of the central forces cause the planet to describe a circle round the Sun?

450. What will be the figure described by the revolving body when these two forces act at right angles to each other, but are not duly adjusted; or when being duly adjusted to each other, they act at oblique angles?

451. Illustrate this subject by means of fig. 17.

452. What must be the projectile velocity of a planet in order that it may revolve round the Sun in a circle?

QUESTIONS AND EXERCISES ON LECTURE X.

453. What is the time in which, by the Earth's rotation on its axis, any given meridian revolves from any fixed star to the same fixed star again, equal to?

454. Why does it require something more than a complete rotation of the Earth on its axis, to bring the same meridian under the Sun on two successive days?

455. What is a solar day?

456. What is a sidereal day?

457. How much does a solar, exceed a sidereal day in length?

458. In 365 solar days, how many complete rotations does the Earth perform on its axis?

459. Proceed to give that very beautiful elucidation of this subject which the 5th diagram affords.

460. Is the phenomenon you have now been describing common to all the primary planets?

461. Are the sidereal days always of the same length?

462. Is there any variation in the length of the solar days?

463. What causes the solar days to vary in length?

464. What is the difference between the time shown by a well-regulated clock, and that shown by a true sun-dial, called?

465. Explain that part of the equation of time which results from the inclination of the Earth's axis to its orbit.

466. How may this be illustrated by a terrestrial globe?
467. Were the obliquity of the ecliptic the only cause of the equation of time, on how many days in the year would a correctly going clock and a true sun-dial agree?
468. Which would those days be?
469. Explain that part of the equation of time which depends on the inequality of the earth's motion in its orbit?
470. How many times in the course of a year would the unequal motion of the earth in its orbit, produce a coincidence between the time shewn by the clock and that shewn by the dial?
471. When would these coincidences take place?
472. What, therefore, will happen when the sun is in apogee and perigee, at his entrance into the signs Aries and Libra, or Cancer and Capricornus?
473. Do the two causes of the equation of time always co-operate in causing the dial to be faster or slower than the clock; or, are their effects sometimes opposed to each other, so that the dial or clock may be faster from one cause and slower from the other, in which case it is reasonable to suppose, they will occasionally counterbalance one another?
474. When one of the equations is faster and the other slower, how is the true equation found?
475. How is it ascertained when they are both faster or both slower?
476. Is the equation of time as already described subject to any variations?
477. Are the variations to which it is subject considerable?
478. From what do they arise?
479. What is the time shown by the sun-dial called?
480. What is the time shown by a well-going clock denominated?
481. What is a sun dial?
482. What is meant by a horizontal dial?

483. What is a vertical or erect dial?
484. What is a vertical dial, whose plane directly faces the north or south, called?
485. Why are those vertical dials, whose planes do not front the north or south, denominated decliners?
486. What are those dials named, the planes of which are neither parallel nor perpendicular to the plane of their horizon?
487. If, moreover, the planes of these dials, besides being oblique to the plane of their horizon, decline from facing the north or south, what are they then termed?
488. What does the face of every sun-dial represent?
489. What does the gnomon or stile represent?
490. Exemplify by means of fig. 18, the universal principle of dialling, with its application to what is called a horizontal dial for any particular place, as London.
491. Explain the application of this universal principle in the case of a vertical direct south dial, as in fig. 19.
492. Explain the method of constructing a horizontal dial by a globe.
493. Describe the method of constructing a horizontal dial, as fig. 21, by the common dialling scale, fig. 20.
494. How may a meridian line be drawn with sufficient accuracy for all common purposes?
495. Why is this operation best performed about the time of the summer solstice?

QUESTIONS AND EXERCISES ON LECTURE XI.

495. What is said of a planet appearing to move according to the order of the signs?
496. What is said of it when its apparent motion is contrary to the order of the signs?
497. What do the aspects of the planets denote?
498. How many aspects are commonly reckoned?

499. Name them, and make the marks by which they are distinguished.
500. What does the sextile aspect imply?
501. What is understood by the quartile aspect?
502. At what distance from each other must two planets be posited to form a trine aspect?
503. When are two planets in opposition?
504. What does the conjunction of two or more planets signify?
505. Are these terms used in reference to any of the other heavenly bodies?
506. By whom are these aspects supposed to have been originally introduced?
507. How were these aspects considered by the ancient astrologers, with regard to their influence on mundane affairs?
508. What did Kepler define an aspect to be, and how many aspects did he introduce in addition to those previously known?
509. Which of the planets are never seen at any great distance from the sun?
510. What appearance does Mercury exhibit when he first becomes visible in the west after sun-set?
511. How may he be distinguished from the fixed stars?
512. What is the greatest elongation or angular distance of Mercury from the sun, at a mean rate?
513. When does Mercury appear for some time stationary?
514. Is the greatest elongation of Mercury constantly the same?
515. Between what limits does it vary?
516. Are the apparent motions of Venus similar to those of Mercury?
517. On what account does the greatest elongation of Venus exceed that of Mercury?
518. Between what limits does the greatest elongation of Venus vary?
519. Why are her stations and retrogradations less frequent than those of Mercury?

520. Explain the phenomena of the interior planets Mercury and Venus, by diagram 6.
521. The illustration now given supposes the earth at rest in one particular point of its orbit, while the planets Mercury and Venus are revolving round the Sun in theirs; this, however, not being the case, but the Earth being also in continual motion round the Sun, explain in what manner the phenomena already described will be affected by the Earth's motion.
522. The greatest elongations of the inferior planets, it has already been observed, are not constantly the same, but vary within certain limits; to what is this variation owing?
523. On what account is it that the inferior planets Mercury and Venus are so seldom seen to pass across the disc of the Sun, when in inferior conjunction with that luminary?
524. In or very near to what points of their orbits must these bodies be situated at the time of their inferior conjunction, in order that this phenomenon may take place?
525. If they be exactly in their node at that time, over what particular point of the Sun's disc will they appear to pass?
526. When either of these planets just touches the limb of the Sun, but without obscuring any part of his disc, what will its geocentric latitude be equal to?
527. When the geocentric latitude of an inferior planet (not exactly in its node) at the time of its inferior conjunction with the Sun, is less than the semi-diameter of that luminary, what appearance will it exhibit to a spectator on the Earth?
528. What will be the case when at the time of conjunction its geocentric latitude exceeds the Sun's semi-diameter?
529. What is the apparent motion of an inferior planet across the disc of the Sun, called?

530. Why are the transits of Venus considered of so much importance in the science of astronomy?
531. What is meant by the parallax of a planet?
532. Explain this by fig. 24.
533. When is the parallax the greatest?
534. With what does it decrease?
535. In what situation has a planet no parallax?
536. Is the effect of parallax similar to that of refraction?
537. Why is it called the parallax of altitude?
538. Can the change of altitude produced by parallax, cause a variation in any other circumstances connected with the place of a planet?
539. Describe the effects of parallax in longitude, latitude, &c.
540. From what does the doctrine of parallax derive its greatest importance?
541. Does the parallax of any object increase or diminish with the distance of that object from the Earth?
542. What celestial bodies are so remote as to have no sensible parallax?
543. Is the parallax of the Sun easily detected?
544. What is the easiest method of determining the parallax of a planet?
545. How may the parallax of the Sun be most accurately determined?
546. By whom was the method of finding the parallax of the Sun from the transits of Venus first suggested?
547. What steps were adopted in consequence of the learned Doctor's suggestions?
548. What advantages has the science of astronomy derived from the observations made on the transits of Venus in the years 1761 and 1769?
549. Explain the general principles upon which this important operation is conducted.
550. Exemplify this by fig. 25.
551. Figure 26 is an illustration of another method of finding the horizontal parallax of the Sun; explain that method.

552. What has been found by a variety of observations to be the Sun's parallax, and consequently what the distance of the Earth from the Sun?
553. The distance of the Earth from the Sun being ascertained, how may the distances of the other planets from that luminary be determined?
554. The distances of the Sun and planets being known, what other particulars respecting those bodies may be easily ascertained?

QUESTIONS AND EXERCISES ON LECTURE XII.

555. What is the aberration of light?
556. By whom was this phenomenon discovered?
557. What was Dr. Bradley endeavouring to determine, when he was led to the discovery of this phenomenon?
558. What has induced astronomers to take so much pains in endeavouring to discover the annual parallax of the fixed stars?
559. In what year was the discovery of the aberration of light completed?
560. What motion of the Earth is demonstrated by this discovery?
561. What deduction of Roemer's was confirmed by it?
562. From observations upon what phenomena did Roemer infer that light was propagated in time and not instantaneously?
563. Explain the phenomenon called the aberration of light by fig. 27.
564. What illustration does a shower of hail afford of this phenomenon?
565. What ought the aberration of the stars near the pole of the ecliptic always to be?
566. In what manner will stars which are situated near the ecliptic itself, be affected by aberration?
567. How will those stars be affected which are situated between the ecliptic and its pole?

568. Are the places of the planets affected by the aberration of light?
569. What is the aberration of a planet equal to?
570. Why is the aberration of the Sun always twenty seconds?
571. How may the aberration of the planets be determined from that of the Sun?
572. In what will the planets' aberration be greatest, and with what will it vary?
573. When is the aberration of a planet the least?
574. When is it greatest in a superior, and when in an inferior planet?
575. What is the precession of the equinoxes?
576. By what is this phenomenon produced?
577. Give an explanation of this phenomenon.
578. In how long do the equinoctial points perform a complete revolution?
579. How much does the Sun's arrival on any year at the same equinox from which he set out the year before, precede the time of his arrival at the same actual point of the heavens from which he started?
580. What is a tropical or solar year?
581. What is a sidereal year?
582. What is the length of each, and what the difference between them?
583. Have all the other planets in like manner a solar and sidereal revolution in their respective orbits?
584. Of the whole annual precession of the equinoxes, how much is produced by the action of the Moon, and how much by that of the Sun?
585. Is there not an inequality in the part of the precession produced by the Moon, and from what causes does this inequality proceed?
586. What other phenomenon may be principally attributed to these causes?
587. By the nutation of the Earth's axis, it describes a small ellipse in the heavens, what are the diameters of this ellipse, what is the period in

which it is described? and with what does this period correspond?

588. To whom are we indebted for the discovery of the nutation of the Earth's axis?

589. With what phenomenon is it combined in producing the change which is observed to take place in the obliquity of the ecliptic?

590. The action of the other planets upon the protuberant matter about the equatorial regions of our Earth, has, in consequence of the inclination of their orbits to the equator, a tendency to diminish the obliquity of the ecliptic, and also to produce a precession of the equinoctial points; to what do their united effects in these cases amount?

QUESTIONS AND EXERCISES ON LECTURE XIII.

591. From what great circle and towards what point of the Earth is the latitude of any place on the Earth's surface reckoned?

592. Why was this circle selected, and was it universally adopted for that purpose by ancient astronomers and geographers?

593. Were they equally unanimous in the choice of a first meridian, and for what purpose is a first meridian used?

594. Through what place did most of the ancient Greek geographers make their first meridian to pass?

595. How was the longitude formerly reckoned?

596. Since what great discovery has the longitude commonly been reckoned both eastward and westward?

597. What other meridians have been fixed on at different times as first meridians?

598. How do modern geographers determine this point?

599. What is commonly understood by the latitude and longitude of a place?

600. What do the words latitude and longitude really mean?

601. Exemplify the misapplication of these terms by modern writers?

602. Is it not probable that these words were originally rather applied to the whole earth itself, than to any particular place on its surface?

603. By what methods may the latitude of any place be found either by day or night?

604. Prove by figure 28. that the height of the pole star, or rather the elevation of the pole, is equal to the latitude of the place.

605. Explain the method of finding the latitude of a place by the meridian altitude of the Sun.

606. May not the latitude of any place be ascertained by taking the meridian altitude of any of the planets or stars whose declinations are known?

607. Why should there be no allowance made for parallax in determining the latitude by the meridian altitude of a star?

608. Describe the manner in which the longitude might be determined with ease by means of a chronometer, provided one could be made which could be depended upon at all times and under every change of climate.

609. In consequence of the variations arising from the difference of climate, &c., to which watches, however correctly made, are found to be subject, other methods are employed for determining the longitude or ascertaining the difference of time at any two distant places; upon what principles do these methods proceed?

610. What celestial phenomena are proper to be employed in determining the longitude?

611. Which of these phenomena are best calculated for this purpose?

612. Who was the first among the Greeks that attempted to determine the magnitude of the Earth?

613. Who next endeavoured to solve this important problem?

614. What means did he employ for this purpose?
615. How did Posidonius endeavour to measure the circumference of the Earth? and what result did he obtain according to Cleomedes?
616. How much does Strabo's account of the circumference of the Earth obtained by Posidonius, differ from that of Cleomedes?
617. How may the difference between these accounts be explained?
618. To whom was the measure of 180,000 stadia, afterwards ascribed by Theon and others, and how came it to be so ascribed?
619. By what more improved method have later astronomers undertaken to determine the magnitude of the Earth?
620. By what means is a degree of the terrestrial meridian measured?
621. Who first attempted this method of determining the circumference of the Earth?
622. What did he find to be the length of a degree; and what did he make the whole circumference of the Earth to be?
623. Who was the first English astronomer that endeavoured to determine the circumference of the Earth by measuring a degree of the meridian?
624. Describe the method by which Mr. Norwood estimated the length of a degree, and his conclusions respecting the dimensions of the Earth.
625. Who was deputed by the Royal Academy of Sciences at Paris to measure a degree of the meridian?
626. Where did he perform this operation? what did he find to be the length of a degree, and consequently, what the circumference of the whole globe?
627. By whom, and to what places was this measurement afterwards continued?
628. From a comparison of the lengths of the several degrees contained in that arc, what very erro-

neous conclusion did Cassini the younger arrive at with respect to the figure of the Earth?

629. What steps did the Academy of Sciences take in order to ascertain whether the Earth were really an oblate or a prolate spheroid?

630. What degree did the mathematicians employed on the northern expedition succeed in measuring, and between what places is it situated?

631. Did they find the length of a degree in these high latitudes to be greater or less than that of a degree in France, and how much?

632. Where, and in what year, did the mathematicians employed in the southern expedition, commence the measurement of a degree?

633. When did they conclude their operations?

634. How much did the length of a degree so near the equator, exceed or fall short of the length of a degree in France?

635. From these measurements and others which have subsequently been made in various parts of the world, is the Earth ascertained to be an oblate or a prolate spheroid?

636. Concerning the exact magnitude of the earth a great difference of opinion still prevails, what, however, may be considered as nearly a true estimate of its circumference and diameter, and also of its superficial and solid contents?

637. Explain the principles upon which the length of a degree in any parallel decreases with the proximity of that parallel to either of the poles, or with its distance from the equator, and also give a proportion for finding the length of a degree in any parallel.

638. From what did the ancient geographers divide the surface of the globe into certain tracts to which they gave the name of climates? and how did they commonly describe the situation of any particular place?

639. What is a geographical climate?

640. Was the whole surface of the Earth divided into climates by the ancients?

641. Did they begin their reckoning at the equator; or with what parallel did they commence?
642. In what direction did they count their climates, and how many climates did they originally reckon?
643. How were they named?
644. Is a climate divided into two equal parts by a parallel, in which the length of the longest day differs a quarter of an hour from that of the longest day in either of the extreme parallels which bound that climate?
645. Why are the parts into which the climate is divided unequal?
646. What number of climates were shortly after added, and on which side of the equator were they situated?
647. How were these southern climates named?
648. How came the whole surface of the earth, from the equator to the poles, to be divided into climates?
649. Where do modern geographers begin to reckon their climates, and how far do they reckon them by the increase of half an hour in the length of the longest day?
650. In what manner are the climates reckoned within the polar circles?
651. Into how many climates is the whole surface of the globe usually divided by modern geographers?
652. What are those climates between the equator and the polar circles called?
653. What are those climates denominated which are situated between the polar circles and the poles?
654. The ancients also divided the surface of the Earth into five great portions called zones; by what particular names were these zones distinguished?
655. What circles form the boundaries of the torrid zone; and what degrees of latitude does that zone comprehend?

656. By what great circle is it divided into two equal parts?
657. How are the temperate zones situated, and what is the latitudinal extent of each?
658. Which are the frigid zones?
659. To what did the terms Amphiscii, Heteroscii, &c., applied by the ancients to the inhabitants of the several zones, refer?
660. Why were those that dwelt within the tropics called Amphiscii?
661. Why were those who lived without the tropics denominated Heteroscii?
662. To whom was the term Periscii applied, and during what time of the year are they properly so called?
663. What were the inhabitants of any place termed when the noon day sun was vertical to them?
664. Why are those who live under the tropics sometimes called Ascii-Heteroscii?
665. Why are the inhabitants of the torrid zone frequently denominated Ascii-Amphiscii?
666. From what other circumstances have peculiar names been given to the inhabitants of different parts of the Earth?
667. To whom did the ancients apply the term Synœci; and what did persons so called have in common?
668. How were the terms Periœci and Antœci applied by the ancient geographers?
669. What did persons so denominated have in common, and in what respect did they differ?
670. To whom do the moderns restrict these terms?
671. In what situation are persons said to be the Antipodes of each other?

QUESTIONS AND EXERCISES ON LECTURE XIV.

672. Can a superior planet ever be seen in opposition to the Sun?
673. Can it ever be in superior conjunction with him?

674. Why can a superior planet never have its unenlightened side wholly turned towards the Earth?
675. Does the motion of a superior planet always appear direct or according to the order of the signs?
676. Give a general description of the phenomena exhibited by a superior planet to a spectator placed on the surface of the Earth?
677. Give a more particular explanation of the apparent motion of a superior planet, illustrating it by diagram 7.
678. Are the phenomena now described common to all the superior planets?
679. Which of these phenomena are greater, the nearer the superior planet is to the Sun?
680. Is the time of retrogradation greater or less the nearer the planet is to the Sun?
681. Describe the increase and decrease which the velocity of the apparent motion of a superior planet undergoes?
682. When is the apparent diameter of a superior planet greatest and when is it least?
683. How do the superior planets appear to move among the fixed stars in consequence of the inclination of their orbits to the plane of the ecliptic?
684. What does fig. 29 represent?
685. How may the apparent path of any other planet be easily delineated?
686. Why is the greater portion of the enlightened surface of a superior planet constantly turned towards the Earth?
687. Describe the phases of the Moon, or the appearances she exhibits in her monthly revolution round the earth.
688. Illustrate this subject by the 8th diagram?
689. What are the syzigies?
690. What are those points of the Moon's orbit in which she is 90 degrees from the Sun, called?
691. What appearances does our Earth present to the inhabitants of the Moon?

692. Can our Earth be ever seen from all parts of the Moon?
693. What is a synodical revolution of the Moon, and by what other name is it sometimes called?
694. What is the mean period of a synodical revolution of the Moon?
695. What is a sidereal revolution of the Moon, and what is its period?
696. What causes the Moon's synodical to exceed her sidereal revolution, and to what is the difference between these two revolutions equal?
697. What is the Moon's periodical revolution, in what time is it performed, and what causes the difference between the sidereal and periodical revolutions?
698. What is the Moon's path in absolute space?
699. Explain the cause of those changes in the form of the lunar orbit, called the lunar inequalities?
700. Explain by means of fig. 30. the alternate acceleration and retardation of the Moon in her orbit, called her variation?
701. By whom was this first observed?
702. Describe the change which takes place in the form of the lunar orbit, in consequence of the Sun's unequal attraction when the Moon is in syzigy and quadrature.
703. The motion of the apsides is also an effect of this disturbing force, describe the phenomenon.
704. In what manner is the line of the Moon's nodes effected by the action of the solar force, in what time do the nodes complete a revolution from any point of the ecliptic to the same point again, and what is their annual motion?
705. Describe the effect of the Sun's attraction on the inclination of the Moon's orbit to the plane of the ecliptic?
706. In what manner are the lunar inequalities affected by the elliptical form of the Earth's orbit?

707. Describe what is termed the Moon's annual equation.
708. By whom was the secular equation first observed?
709. By whom was the cause of this inequality discovered?
710. Explain the nature of it.
711. How is the correction for the Moon's longitude calculated by the present tables, found?
712. In what time does the Moon revolve on her axis, and how is it ascertained?
713. How is that side of the Moon which is turned towards the Earth, enlightened during the absence of the Sun?
714. What proportion of light and darkness has the other side of the Moon?
715. What is the length of a lunar natural day, and what diversity of seasons do the inhabitants of the Moon experience?
716. In what manner will the lunarians probably determine the length of their year?
717. How many natural days does it consist of?
718. What is meant by the Moon's libration, of how many kinds is it; and by what names are the different species of libration distinguished?
719. Do these different species of libration arise from real inequalities in the Moon's rotation on her axis, or are they only apparent irregularities?
720. By whom were they discovered?
721. Whence does the libration in longitude arise?
722. Explain this phenomenon.
723. What causes the Moon's libration in latitude?
724. Explain the nature of her diurnal libration.
725. How is the spheroidal libration caused?
726. Explain the phenomenon called the Harvest Moon.
727. Why is it that this phenomenon, which happens every lunation, is only taken notice of in the harvest months?
728. Describe the manner in which the phenomenon of the Harvest Moon is affected by the inclina-

tion of the Moon's orbit and the place of her nodes.

729. Which is the Harvest Moon to the inhabitants of the southern hemisphere?

730. Why does the Moon when near the horizon appear so much larger than when in the zenith?

QUESTIONS AND EXERCISES ON LECTURE XV.

731. What is an eclipse of the Moon?

732. What is an eclipse of the Sun, as it is commonly called?

733. What did the ancients believe an eclipse of the Sun to be caused by?

734. Why was an eclipse of the Moon frequently called by the ancients *lunæ labores*.

735. Of what use are these phenomena in chronology?

736. Does the science of geography receive any benefit from them?

737. What effect is produced by the interception of the rays of light, issuing from a luminous body, by an opaque one?

738. What figure will the shadow cast by an opaque spherical body assume, when the luminous body is inferior to the opaque one in magnitude?

739. When the luminous body is equal in size to the opaque one, what will be the figure of the shadow cast by the latter?

740. In either of the above cases, what will be the length of the shadow?

741. If the magnitude of the luminous body exceed that of the body illuminated, what form will the shadow of the latter be of?

742. What is that fainter divergent shade called, which encompasses the conical shadow cast by an opaque body, whose magnitude is less than that of the luminous body by which it is illuminated?

743. What is the figure of the penumbra, and with what does its axis coincide?
744. Explain these particulars by fig. 32.
745. Why is the shadow cast by every planet and satellite in the system of a conical form?
746. In what situation of a planet is the shadow cast by it the longest?
747. When is it shortest?
748. Explain by fig. 33 the cause of solar and lunar eclipses?
749. Why is it that there is not an eclipse of the Sun every time the Moon is new or in conjunction; and an eclipse of the Moon every time she is full or in opposition?
750. In or near to what point of her orbit must the Moon be at the time of new and full Moon, in order that these phenomena may take place?
751. When the Moon is exactly in her node at the time of new or full Moon, what two lines coincide?
752. If the new Moon take place exactly in the node, what kind of eclipse of the Sun will happen?
753. How will the Moon be eclipsed if at the time of full Moon the line of her nodes precisely coincides with the line of the syzigies?
754. Within how many degrees of her node must the Moon be at the time of her conjunction, in order that a solar eclipse may take place?
755. Within how many degrees of her node at the time of opposition must the Moon be situated, in order that a lunar eclipse may happen?
756. Why can there be neither a solar nor a lunar eclipse when the Moon's distance from her node exceeds those limits?
757. Exemplify these particulars by diagram 9.
758. When the line of the nodes coincides with the line of the syzigies, where is the Moon at new and full, and how is she situated about her quarters?
759. How is the Moon situated when new and full,

and in what points of her orbit is she about her quarters, when the line of the nodes is at right angles to the line of the syzigies?

760. Does the line of the Moon's nodes always continue parallel to itself?

761. What does the motion of the nodes amount to in a lunation, and what in a year, and this motion being retrograde, how many days sooner does the Sun arrive at the same node each successive year, than he did on the year preceding?

762. In what time do the nodes perform a complete revolution in the ecliptic, and why cannot the period of their revolution be employed as a regular period of eclipses?

763. What number of lunations does the Chaldaic period comprehend, and of what number of years, days, &c. does it consist?

764. In what manner did the ancients employ this period in calculating the return of eclipses?

765. A much more exact period than the Chaldaic may however be used in a similar manner for predicting the return of eclipses; what is the absolute length of this period? of how many lunations does it consist? also, what will be the Moon's distance at the conclusion of it from the position which she had relatively to the Sun and Earth at its commencement?

766. What is the least and what the greatest number of eclipses that can happen in the course of any year?

767. When only two eclipses take place, of what kind will they be?

768. When seven happen in one year, how many of them will be solar and how many lunar?

769. What is the most usual number, and how many of them are lunar?

770. Explain the cause of this variety in the number of eclipses which may happen in the course of a year?

771. Where do eclipses of the Sun begin and end?

772. On which limb do eclipses of the Moon commence, and where do they go off?

773. Into how many parts is the disc of the body eclipsed, supposed to be divided? what are those divisions called? and how is the quantity of an eclipse expressed?

774 The Moon's orbit being elliptical, and the Earth occupying one of the foci of the ellipse, in what points of her orbit is the Moon's apparent diameter exactly equal to that of the Sun? when is it less than the Sun's diameter, and when is it greater?

775. The diameter, therefore, of the Moon constantly varying with her distance from the Earth, explain in what manner an eclipse of the Sun (which, we have already seen, always happens when the moon changes very near her node) is affected by the Moon's distance from the Earth at the time of the eclipse taking place?

776. Why, in a solar eclipse, can total darkness never continue more than 4 minutes 6 seconds?

777. What is the diameter of the circular space on the Earth's surface, over which the Moon's dark shadow extends, when the Sun is farthest from the Earth and the Moon nearest to it; that is, when this space is the largest possible?

778. How far may the penumbra extend upon the surface of the Earth?

779. Under what circumstances are the shadow and penumbra falling upon the Earth exactly circular?

780. What effect has the Moon's parallax upon a solar eclipse?

781. Why does not an eclipse of the Sun occur at the same time in all places to which it becomes visible?

782. The velocity with which the Moon's shadow traverses the Earth's surface, is equal to that of the Moon's motion from the Sun; to how many English miles per hour does this amount?

783. Illustrate the phenomena of solar eclipses by figs. 34, 35, and 36.
784. Explain the manner in which the penumbra falls upon the Earth in respect of the latitude of the Moon, and her proximity to her node?
785. Illustrate the subject of lunar eclipses by fig. 34.
786. When the Moon is full exactly in her node, through what point of the Earth's shadow does she pass, and what is her distance from her node, when she just touches the Earth's shadow without entering into it?
787. What is the greatest possible duration of a lunar eclipse?
788. What is meant by the Moon's being more than 12 digits eclipsed?
789. In what manner is the quantity of an eclipse frequently expressed by modern astronomers?
790. What causes the Moon sometimes to appear of a dusky red colour, when totally immersed in the Earth's shadow?
791. What is meant by an occultation of a star or planet?
792. Explain the circumstances under which these phenomena may happen.

QUESTIONS AND EXERCISES ON LECTURE XVI.

793. What is the word tide usually employed to denote?
794. Who is generally supposed to have first assigned the true cause of the tides?
795. By whom was it afterwards demonstrated that these phenomena are precisely such as ought to result from the action of the Sun and Moon upon the waters of this terraqueous globe?
796. How may it be known that the tides are principally under the influence of the Moon?
797. Explain by the 37th and three following figures the manner in which the Moon (separately considered) acts upon the waters of the ocean in

producing the general phenomena of the tides?

798. Are the tides wholly under the influence of the Moon?

799. In the production of the tides, what proportion does the disturbing force of the Sun bear to that of the Moon?

800. Exemplify by figs. 41 and 42, the effects of the Sun and Moon in producing the phenomena called Spring and Neap tides.

801. Why is it that it is never high water at any place at the time of the Moon's passing the meridian of that place, but some hours after, when, according to the explanation now given, the tides ought to be highest immediately under the Moon, and on the opposite side of the Earth? also, why do the Spring and Neap tides never happen till a few days after the Moon's being in syzygy and quadrature?

802. Explain the modifications (principally arising from the obliquity of the ecliptic, and the inclination of the Moon's orbit to the plane of the equator) to which the general phenomena of the tides, as now explained, are subject.

803. To what local circumstances may be attributed that want of conformity which is observable in the tides at particular places, to the general theory already laid down?

804. Explain by figures 43 and 44 the apparent motions of Jupiter's satellites?

805. What are the geocentric nodes of these satellites?

806. What line does the satellite appear to describe when the Earth is in either of its geocentric nodes?

807. What will be the apparent path of the planet when the Earth is in any other situation?

808. How may it be known when a satellite is in its superior or inferior semicircle?

809. Jupiter being supposed at his mean distance

from the Earth, what is the greatest angular distance of each of his satellites from him?

810. In going through their inferior semicircle, what appearance do they sometimes exhibit?

811. In going through their superior semicircle, the satellites of Jupiter are eclipsed by passing through his shadow; they also sometimes suffer an occultation, or are hidden behind the body of their primary without being eclipsed; explain these phenomena by fig. 45.

812. From what is it inferred that the planes of the orbits of Jupiter's satellites do not coincide with that of their primary?

813. What are the eclipses of these satellites frequently employed for determining?

814. What discovery did Roemer make from observations upon the eclipses of Jupiter's satellites?

815. Exemplify this subject by fig. 45.

816. Why do the satellites of Saturn so seldom pass through the shadow of their primary?

817. What is the inclination of the plane of Saturn's ring to the plane of his own orbit?

818. Why is it that the Sun constantly illumines the north side or upper surface of the ring during one half of the Saturnian year, and the south side or lower surface of it during the other?

819. From what cause does the ring disappear twice in the course of every revolution of Saturn about the Sun, and what is the longitude of Saturn when this is observed to happen?

820. Illustrate the phenomena of Saturn's ring by fig. 46.

821. What occasions the ring sometimes to disappear twice in the course of one of our years?

822. What is meant by the disappearance of the ring, since Dr. Herschell informs us, that when Saturn was observed through his forty feet reflector, the ring was always visible?

823. What other curious phenomenon has Dr. Herschell sometimes witnessed through the same very powerful instrument?

824. Who records an instance of a star having been seen through the space between the ring of Saturn and the body of that planet?

QUESTIONS AND EXERCISES ON LECTURE XVII.

825. In what light were Comets generally regarded by the ancients?
826. What is said to have been the opinion of the ancient Chaldeans respecting them?
827. What did Pythagoras maintain concerning them?
828. Was Aristotle of the same opinion?
829. What did Seneca suppose these bodies to be, and in what manner does he argue respecting them?
830. Who first proved by direct observation, that Comets were situated at a much greater distance from the Earth than the orbit of the Moon, and consequently could not be meteors or exhalations?
831. Who fully demonstrated that Comets were planetary bodies revolving about the Sun in very eccentric ellipses, which extend far beyond the planetary system?
832. Describe the telescopic appearance of the head of a Comet?
833. Do the heads of all Comets present similar appearances?
834. What very peculiar appearances did the nucleus of the Comet of 1618 exhibit?
835. What did Sir Isaac Newton suppose the nuclei of Comets to be composed of?
836. What was the opinion of Appian, Cardan, Tycho, and others respecting them, and what did they suppose the tails of Comets to be?
837. Of what did Kepler imagine the tail of a Comet to consist?
838. What was the opinion of Des Cartes respecting it?
839. What very eminent astronomer supposed the tail

of a Comet to consist of a very fine vapour, exhaled from the nucleus by the intense heat of the Sun?

838. Describe the various appearances the tail of a Comet exhibits, in consequence of the position of the Comet itself, relatively to the Sun and Earth?

839. How long was the tail of the remarkable Comet of 1680, according to Sir Isaac Newton?

840. What remarkable appearance was observed by Hevelius, in the Comet of 1665; and what other Comets have exhibited similar appearances?

841. Why may that part of its orbit which a Comet describes, when visible, be considered a portion of a parabola?

842. With what velocity did the Comet of 1680 move in its perihelion, according to Sir Isaac Newton?

843. For what is the Comet of 1759 remarkable, and by whom was its return foretold?

844. What is supposed to be its period, and when may it again be expected to make its appearance?

845. What did Dr. Halley suppose to be the period of the famous Comet of 1680? in what years did he suppose it to have been previously seen, and by what celebrated poet of antiquity is the same Comet probably alluded to?

846. What was remarkable in the Comet of 1770?

847. What was the diameter of the nucleus of the Comet of 1811 in geographical miles, according to Schroeter, and what was the diameter of a smaller and much more brilliant nucleus, which the same astronomer observed in the centre of the former?

848. What was the total diameter of the head of this Comet, and what the greatest length of the tail, according to the same observer?

849. Of twenty-four Comets whose elements have been accurately calculated, how many have passed between the Sun and the orbit of Mercury

—how many between the orbits of Mercury and Venus — how many between the orbits of Venus and the Earth — how many between the orbits of the Earth and Mars — how many between the orbits of Mars and Ceres — and how many between the orbits of Ceres and Jupiter?

850. Show how improbable it is that any Comet in its passage to or from its perihelion should encounter the Earth, or make so near an appulse to it, as to cause any serious convulsion, or be attended with any calamitous consequences?

851. To what did Mr. Whiston attribute the universal deluge in the time of Noah?

852. What very extraordinary opinion was entertained by that gentleman with respect to the purposes for which these bodies were probably designed?

QUESTIONS AND EXERCISES ON LECTURE XVIII.

853. How may the fixed stars be readily distinguished from the planets?

854. How do you account for the twinkling of the fixed stars?

855. What is the greatest number of stars at any one time visible to the naked eye?

856. Whence may the diversity in the apparent magnitudes of the fixed stars be supposed to arise?

857. Into how many classes or orders are the fixed stars which are visible to the naked eye divided by astronomers, with respect to their apparent magnitudes? and what are those stars denominated which compose the several classes?

858. Are the stars composing any one of these classes all of the same apparent size and brightness?

859. What are those stars called which cannot be perceived without the aid of a telescope?

860. In what manner was the sphere of the fixed stars divided by the ancients?

861. What proof have you to offer of the antiquity of

this method of dividing the stars into constellations?

862. What was the number of the ancient constellations, (as they are now called,) and in what manner were they for the most part delineated?

863. By what general name were those stars called which could not be included in any of the figures of the constellations?

864. What is the number of the constellations into which the heavens are at present divided, and of what are the new constellations principally composed?

865. Into how many classes are the constellations usually divided, and what does each class comprehend?

866. To what number do the constellations north of the zodiac at present amount?

867. What is the number of constellations south of the zodiac?

868. What farther distinctions were employed by the ancients in regard to these bodies?

869. What very effectual method of distinguishing the several stars contained in each constellation was introduced by Bayer about the year 1603?

870. Do the Greek letters indicate the real magnitudes of the stars to which they refer, or only the relative magnitudes of those in the same constellation?

871. For what purpose were the letters of the Roman alphabet employed?

872. When the number of stars in any constellation exceeds the number of letters contained in both alphabets, how are the references continued?

873. Under what form are each of the Bears said to have been represented by the ancients; and by what other names is the constellation commonly called the Great Bear still very frequently distinguished?

874. In what manner are the seven stars disposed,

by which this constellation is principally known?

875. Why are the two stars farthest from the tail called the *pointers*, and which of them is of the 1st magnitude?

876. Which of the seven principal stars in this constellation have proper names assigned them; and what are those names?

877. Which of the stars in the tail of the Great Bear appears double? and what is the star of the 5th magnitude called, from which it derives this appearance?

878. Describe the position of the principal stars in Ursa Minor.

879. Why is the star at the extremity of the tail of the Little Bear called the *Pole Star*?

880. Which of the stars in this constellation are denominated the *Wardens of the Pole*; and by what particular name is the brightest of these two stars distinguished?

881. In what form are the principal stars in the constellation Cassiopeia arranged; what is the first star called; and how may this star, and consequently the whole constellation be readily found in the heavens?

882. Describe the situation of the principal stars in the constellation Cepheus, with the most ready means of finding them in the heavens.

883. Describe the situation of the constellation Draco.

884. What star in this constellation passes vertically over London once in the course of a natural day; in what part of the Dragon is the most brilliant star in the constellation situated, and how may it be distinguished in the heavens?

885. What remarkable star is contained in the constellation Auriga, and in what part of the constellation is it found?

886. Describe the situation of the other principal stars in Auriga, and by what means they may be known?

887. How is Andromeda represented; what particular stars does it contain; where are they situated, and how may they be distinguished?

888. In what constellation are *Algenib* and *Algol* situated, and by what means may they be found?

889. How are the Triangles and the Northern Fly situated?

890. How many stars of the 2d magnitude does Pegasus contain; what are their names, and what do they form with *Alpheratz* in the head of Andromeda; also, what is the particular situation of each of these stars, and in what part of the constellation is the star *Enif* situated?

891. How may Delphinus be known?

892. What star of the 1st magnitude is to be found in the constellation of the Swan; in what form are the principal stars in this constellation disposed; and in what part of the figure formed by them does the star of the 1st magnitude occur?

893. The Eagle and Antinöus are generally considered as one constellation, which is intersected by the equinoctial: what portion of this constellation is north of that circle, and what portion is south of it?

894. In what manner are constellations, which are divided into two parts each by the equinoctial, to be looked for in the planispheres?

895. *Athair* is a star of the 1st magnitude in the Eagle; describe the situation of this star, and of the other principal stars in the same constellation.

896. How does Sagitta lie from Aquila?

897. In what constellation is the beautiful star *Vega* or *Wega* situated; and how may it be found?

898. What is the name of the principal star in the Northern Crown?

899. How is Hercules represented, and in what part is *Ras Algethi* situated?
900. The Serpent Bearer and the Serpent contain a star of the 2d magnitude each: how are these stars situated, and what is the name of that in the Serpent Bearer?
901. How is the constellation Böotes represented, and for what brilliant star is it remarkable?
902. Describe the situation of this and the other principal stars contained in this asterism?
903. Between what constellations are the Greyhounds situated?
904. Where is Cor Caroli, and by whom was it made a constellation?
905. How is Coma Berenices situated, and of what stars does it principally consist?
906. Describe the situation of the principal stars in Leo Minor.

QUESTIONS AND EXERCISES ON LECTURE XIX.

907. How are the principal stars in Aries situated?
908. What two remarkable groups of stars are contained in the Bull?
909. What is the chief star in this constellation named, and what part of the figure does it form?
910. What are the two principal stars in Gemini called?
911. Describe the situation of these stars, and of the other principal stars in the same constellation.
912. How may the principal stars in Cancer be recognised; and what are two remarkable stars in the body of the Crab called?
913. How many stars of the 1st magnitude are there in Leo; what are their names; in what parts of the constellation are they situated, and how may they be readily found in the heavens?
914. How is the Virgin represented; where is the star

Spica; what is its magnitude, and how may it be recognised?

915. What are the two principal stars in Libra called, and how are they situated?

916. In which scale is *Zuben Hakrabi*, and with what other stars does it form a rhomboid?

917. How may *Antares*, the chief star in the Scorpion, be distinguished, and for what is it remarkable?

918. How are the principal stars in Sagittarius (most of which are visible in our latitudes) situated?

919. The Goat is principally distinguished by three stars of the 3d magnitude: describe their situation, and also that of *Deneb Algedi*, a star of the 4th magnitude in the same asterism.

920. Give directions for recognising the principal stars in Aquarius.

921. In what part of the constellation Pisces is its chief star situated; what is its magnitude, and how may its position in the heavens be determined?

922. For what is the constellation Cetus remarkable?

923. Some of the stars in this constellation have proper names: what are the names by which they are distinguished, and in what parts of the Whale are they to be found; also, what is the magnitude of the principal stars in the asterism?

924. Name the three modern constellations which are situated immediately below the Whale?

925. For what is the constellation Orion remarkable, and how is it usually represented?

926. How many stars of the first magnitude, how many of the 2d, and how many of the 3d, are contained in this brilliant asterism?

927. Describe the situation of the nine principal stars in Orion.

928. How is the constellation Lepus situated?

929. Describe the course of the river Po?
930. What is the chief star in this constellation called, and why is it never seen by the inhabitants of Great Britain?
931. What is the name of the principal star in Canis Minor; what is its magnitude; and how may its situation in the heavens be determined?
932. What is the principal star in Argo Navis called, and how is it situated; also, in what part of the Ship is the star *Markab*, and what star of the 1st magnitude is it nearly south of?
933. In what constellation is the star *Sirius*, for what is it remarkable, and with what others does it form a triangle nearly equilateral?
934. What is remarkable in the constellation Hydra; what is the name, and what the magnitude of its chief star, and where is that star situated?
935. How are the Cup, the Crow, and the Bird of the Desert situated?
936. The only stars of consequence in the Centaur that ever ascend above our horizon are one of the 2d magnitude, one of the 3d, and four of the 4th: how are the stars disposed in the constellation?
937. In what constellation is *Fomalhaut*; what part of the constellation does it form, and what star is it due south of?
938. Among those constellations which are always invisible to the inhabitants of Great Britain, the Cross is the most brilliant and the most remarkable: of what principal stars does it consist, and what advantages do the inhabitants of the southern hemisphere derive from it?
939. In describing the positions of the several stars contained in any constellation, how is the constellation itself supposed to be situated?
940. How do you discover what stars culminate or come to the meridian at any given time?

QUESTIONS AND EXERCISES ON LECTURE XX.

941. In what respect does the telescopic appearance of the fixed stars prove the immeasurable distance of those bodies from us.
942. By what method did Dr. Bradley endeavour to discover the annual parallax of the fixed stars?
943. What result did he obtain?
944. Was Dr. Herschel, who endeavoured to determine the same problem by observations upon double stars, more successful?
945. Explain the very ingenious method proposed by Mr. Mitchell, for obtaining the probable parallax of the fixed stars.
946. Why cannot the results obtained by this method be relied on?
947. What means have been employed by astronomers for detecting any changes which may be going on among the fixed stars, but which, on account of the very immense distance of those bodies, require very long periods of time to become sensible?
948. Who first made a catalogue of the fixed stars?
949. By whom was the most extensive catalogue of the stars formed, and what number did it comprehend?
950. By whom was the proper motion of the fixed stars first discovered?
951. Who first ascribed this phenomenon to a progressive motion of the solar system, and from what considerations did he deduce this opinion?
952. Towards what point of the heavens does Dr. Herschel suppose this motion of the solar system directed?
953. What does Dr. Herschel imagine to be the velocity of this motion, and of what does he suppose the centre round which it is performed to consist?
954. What discovery induced Hipparchus to undertake the task of forming a catalogue of the stars?

955. When was a new star discovered in Cassiopeia?
956. By whom was it particularly observed?
957. What appearance did it exhibit when it was first seen?
958. When did its magnitude begin to diminish?
959. When did it entirely disappear, and how long had it been visible?
960. What new star exhibited similar appearances?
961. By whom was it observed, and in what year?
962. In what part of the heavens was it seen?
963. What star affords an example of those which are gradually increasing in brightness?
964. Give an example of some star whose lustre is gradually decreasing.
965. Some stars are found to undergo a periodical variation of lustre: mention some examples of this kind.
966. What number of stars are ascertained to be variable, and how many are supposed by Herschel to be subject to these changes?
967. Mention a few of the various hypotheses which have been proposed to account for these phenomena.
968. How many stars have been observed in the constellation Orion, by the aid of very powerful telescopes?
969. What surprising number of stars has Dr. Herschel seen pass through the field of view of his telescope in one quarter of an hour's time, when examining the most crowded part of the Milky Way?
970. What stars does Dr. Herschel call insulated, and by what does he suppose them attended?
971. What stars are comprehended by Dr. Herschel under the term double stars, or binary sidereal systems?
972. How may two stars be so disposed as to have the appearance of a double star, without actually forming a binary system?
973. What was Dr. Herschel's opinion upon this subject?

974. What does Dr. Herschel call the *angle of position* in a double star?

975. In how many double stars upon which observations have been made by the Doctor has he found a change either in the angle of position or in the distance between the two stars of which the double star is composed?

976. Six double stars upon which the Doctor's observations have been published afford a very interesting specimen of these phenomena: which stars are they?

977. Into how many classes has Dr. Herschel divided double stars; and what is the distinguishing characteristic of each class?

978. What are nebulæ?

979. Which is the most remarkable phenomenon of this kind?

980. From what does the whiteness of the Milky Way arise?

981. What does Dr. Herschel suppose the Milky Way to be?

982. Who first suggested the idea that all the stars throughout the universe were collected into nebulæ, and that all the insulated and scattered stars which appear in the heavens belong to that particular nebula in which the solar system is placed?

983. By whom was the truth of this theory established?

984. Of how many nebulæ has Dr. Herschel determined the position, magnitude, and structure?

985. Describe some of the varieties under which they appear?

986. What further observations did Dr. Herschel make respecting these phenomena, and by what means does he suppose the condensation of the stars into nebulæ is effected?

987. What are *nebulous stars*?

988. Of what does Dr. Herschel suppose the nebulosity which accompanies these stars to be com-

posed, and what does he imagine the bright central spot or star to be?

989. Among the numerous nebulæ which have been already discovered, how are some of the most remarkable situated?

990. Describe the arrangement of the heavenly bodies according to the Ptolemaic system of the heavens.

991. In what manner did the Ptolemaic hypothesis explain the apparent diurnal revolution of these bodies?

992. How were the direct, stationary, and retrograde appearances of the planets, and the inclinations of their respective orbits to the ecliptic, accounted for upon this hypothesis?

993. How were the inequalities in the sun's annual motion and the variation in his apparent diameter explained?

994. What peculiarities in the phenomena of the inferior planets could not be accounted for upon the Ptolemaic hypothesis?

995. In what respects did the Egyptian system differ from the Ptolemaic?

996. How was the Tychonic system distinguished from the preceding, and what very considerable improvement did it receive from Longomontanus?

997. By whom was the true system of the heavens (first taught by Pythagoras) restored? and in what important particulars does this system differ from all the foregoing?

998. The Earth's diurnal rotation on its axis, and its annual revolution in its orbit, being the two grand principles upon which the Copernican system rests, in demonstrating the truth of this system, it will be necessary to prove the existence of these motions, to the former of which several objections have occasionally been urged by the opponents of the Copernican hypothesis; these,

however, may, for the most part, be reduced to three: what are they?

999. How may these objections be severally answered?

1000. Prove the annual motion of the Earth round the Sun.

PROBLEMS AND EXERCISES

ON THE

ASTRONOMICON.

PROBLEM I.

To find the Sun's place (commonly called his longitude) in the ecliptic, and thence his real situation in the heavens, on any given day.

Seek the day of the month in the calendar of months, and against it in the adjoining circle will be found the Sun's longitude or place in the ecliptic for that day: observe whether this be among the northern or southern signs, and find the same sign and degree in the ecliptic, on the map of the northern or southern hemisphere accordingly: this will be the place of the Sun on the map, and by consequence, in the heavens, for that day at noon.

Thus the Sun's longitude or place in the ecliptic on the 7th July is about 15½° of Cancer, and consequently his place in the heavens is in the middle of the constellation Gemini, near to the star in Castor's right elbow.

QUESTIONS FOR EXERCISE.

Required the Sun's longitude and place in the heavens on the following days; 21st June, 21st December, 16th April, 4th October, and 28th January.

PROBLEM II.

The Sun's place in the ecliptic or in the heavens being given, to find the day of the month.

If the Sun's longitude or place in the ecliptic be given, seek, in the calendar of months, the corresponding day to that longitude for the answer.

But if his place in the heavens be given, find that place on one of the maps, and observe to what degree of the ecliptic it answers: the day corresponding with this degree in the calendar of months is the day sought.

Thus, suppose the day on which the Sun is due north of the star, in the tip of the Bull's southern horn, be required,—the point of the ecliptic (in which circle the Sun must always be found) north of this star is between 21 and 22 degrees of Gemini, and consequently the day required is the 12th of June.

QUESTIONS FOR EXERCISE.

What are the days of the month in which the Sun is respectively in the 12th degree of the twelve signs of the zodiac?

On what day will the Sun pass the star Regulus in Leo?

When will Zuben el Genubi be in conjunction with the Sun?

PROBLEM III.

To find the right ascension of the Sun or any fixed star.

Extend the silk string over the Sun's place, or over the given star, and it will cut the right ascension in time or degrees, among the divisions on the circumference of the map.

Thus, the Sun's right ascension on the 21st of June is 90 degrees, or VI hours.

QUESTIONS FOR EXERCISE.

What is the right ascension of the Sun on the following days; 4th June, 15th May, 10th October?

Required the right ascension of *Aldebaran* in Taurus, *Etanin* in Draco, *Arcturus* in Böotes?

PROBLEM IV.

To find the declination of the Sun or any fixed star.

Bring the silk string over the Sun's place or over the given star, and extend it to the equinoctial or circumference of the map as in the last problem, then with a pair of compasses take the distance of the Sun's place, or of the star from the point of the equinoctial intersected by the string: this distance, referred to the graduated quadrant of the equinoctial colure, will give the declination required.

Thus the Sun's declination on the 21st of December is 23½ S.

QUESTIONS FOR EXERCISE.

What is the Sun's declination on the 10th July?

Required the declination of *Antares* in Scorpio, *Schedir* in Cassiopeia, *Vega* in Lyra, and *Sirius* in Canis Major?

PROBLEM V.

The right ascension and declination of any star being given, to find that star.

Find the right ascension on the equinoctial, and extend the silk string over that point, then taking the declination between the points of your compasses from the graduated quadrant of the equinoctial colure, place one foot of the compasses in that point of the equinoctial which is cut by the string, and extend the other towards the pole: the star upon which that point of the compasses falls will be the one required.

Thus the star whose right ascension is 149 degrees, and declination about 13 degrees north, is *Regulus* in Leo.

QUESTIONS FOR EXERCISE.

Required the stars whose right ascensions and declinations are nearly as follow:

Right Ascension.	Declination.
210°	20° N.
43°	40° N.
76°	8½° S.
243°	26° S.
342°	31° S.
162°	57° N.

PROBLEM VI.

In any proposed latitude to find the meridian altitude of the Sun, or of any given fixed star.

Find the declination of the Sun or star by problem iv.: this added to or subtracted from the complement of the latitude, according as the latitude and declination are of the same or different denominations, will give the meridian altitude required.

Thus, suppose it be required to find the meridian altitude of Regulus in Leo.

The latitude of London is about 51½°, its complement 38½°, hence 38½° + 13° (the declination of *Regulus* nearly) equal 51½°, the meridian altitude required.

QUESTIONS FOR EXERCISE.

Required the Sun's meridian altitude on the following days; 10th July, 14th Aug. and 29th Sept.?

What is the meridian altitude of *Sirius*?

Required the meridian altitude of *Capella*, the latitude of the place of observation being 56° N.

What is the meridian altitude of *Spica*, in latitude 10½° S.?

PROBLEM VII.

To find all those stars which have the same declination as any given star, or to find all those stars which have a given declination.

Through the given star or given declination, de-

scribe a circle from the pole as a centre, and it will pass over the stars sought.

Thus, if we wish to find all those stars which have the same declination as Capella in Auriga, a circle described from the North Pole through that star cuts the stars required.

QUESTIONS FOR EXERCISE.

What stars have nearly the same declination as Sirius?

It is required to find all those stars whose declination is the same as that of the Sun on the following days; 21st June, 21st December, 20th March, 23d September, 1st February, and the 1st August.

PROBLEM VIII.

To describe the circle of perpetual apparition of any given place, or to find all those stars which never set at that place.

From the Pole of that hemisphere, which is of the same denomination as the latitude of the given place, describe a circle through a declination equal to the complement of that latitude; this circle will be the circle of perpetual apparition required, and will comprehend all those stars which never set at the proposed place.

Thus, suppose it were required to find all the stars which never set at Paris. The latitude of Paris being 48° 50′ N. the declination through which the circle of perpetual apparition must pass is 41° 10′ N.

QUESTIONS FOR EXERCISE.

It is required to show on the maps, the stars which never set at the following places: Rome, lat. 41° 54′. N.; St. Petersburg, lat. 56° 56′. N.; St. Salvador, lat. 12° 58′. S.; St. Helena, lat. 15° 55′ S.; and at the North and South Poles.

PROBLEM IX.

To describe the circle of perpetual occultation of

any given place, or to find all those stars which never rise at that place.

From the Pole of that hemisphere which is of a contrary denomination to the latitude of the given place describe a circle through a declination equal to the complement of that latitude: this circle will be the circle of perpetual occultation required, and will comprehend all those stars which never rise at the proposed place.

Thus the circle of perpetual occultation of Paris, or that circle which comprehends all those stars which never ascend above the horizon of that place, must pass through the declination of 41° 10'. S.

QUESTIONS FOR EXERCISE.

It is required to show on the maps the stars which never rise at the following places: viz. Aleppo, lat. 35° 40'. N.; Quebec, 46° 47'. N.; Staten Land, 54° 50'. S.; Natal, lat. 29° S.

How are those places situated to which the arctic circle becomes the circle of perpetual occultation?

PROBLEM X.

To find those stars which pass through the zenith of any given place.

From the pole of that hemisphere, which is of the same denomination with the latitude of the given place, describe a circle passing through a declination equal to that latitude: this circle will cut all those stars which come to the zenith of the proposed place.

Thus, a circle described from the North Pole, through the declination of 51½°, will pass through all those stars which come to the zenith of London.

QUESTIONS FOR EXERCISE.

What stars become vertical once in every natural day to the following places: Douglas, lat. 54° 5' N.; Granada, lat. 37° 8' N.; Gozi, lat. 34° 50' N.; Sable Cape, lat. 43° 30'; Easter Island, 27° 6' S.; Papudo, lat. 32° 36' S.?

PROBLEM XI.

To find what stars are on the meridian, or directly north and south at any given time.*

Having found by problems i. and iii. the Sun's place and right ascension for the given day, in the map of the northern or southern hemisphere, according as his declination is north or south of the equinoctial, consider whether the given time be before or after noon; if the former, move the silk string backwards so many hours, &c. as the proposed time wants of noon, but if the latter, advance it forward so many hours as the time given is past noon, then, letting the string remain in this position, observe what degree of right ascension is now cut by it, and extend the silk string from the centre of the other planisphere over the corresponding degree on its circumference. The strings thus disposed form a complete meridian on the two maps, extending from the north to the south pole, and passing over the stars which are on the meridian at the given time. We have, however, already seen that those stars which are within the circle of perpetual occultation can never be visible in our latitudes, while, on the contrary, those comprehended by the circle of perpetual apparition never set; to complete this problem, therefore, the string on the map of the northern hemisphere, must be imagined to extend through the pole to the opposite point of the circle of perpetual apparition, while the string on the map of the southern hemisphere may be supposed to terminate when it touches the circle of perpetual occultation.

Thus, on the 1st of November, at 8 o'clock in the evening, the meridian from north to south is occupied by Ursa Major, the tail Draco, the head of Camelopardalis, Cepheus, the fore legs and head of Pegasus, Aquarius, and Piscis Australis.

* This problem has been already introduced in Lecture XIX. p. 369.

QUESTIONS FOR EXERCISE.

What star of the 1st magnitude culminates at 9 o'clock in the evening on the 10th of January?

What constellations and principal stars are in the meridian on the first day of every month respectively throughout the year, at 10 o'clock in the evening?

The longitude and latitude of the stars may be found very near the truth, by referring to the poles of the ecliptic, instead of those of the equinoctial.

In the same manner, also, the place of the planets (their longitude and latitude being taken from *White's Ephemeris*) may be marked upon the maps, and the place of any planet being ascertained, its right ascension and declination, time of culminating, &c. may be found by the problems already given for the fixed stars.

The following problems are adapted to the moveable planisphere of the stars visible in the latitude of London. *

* It may be proper to observe, that this planisphere formed no part of the illustrations originally intended to accompany this work, and has only been introduced *since* the Lectures, together with the Questions and Exercises upon them, were printed off. The Author's chief design in making this important addition to the Astronomicon was to facilitate the progress of the Student in acquiring a thorough knowledge of the Constellations, and of the principal stars contained in each, by presenting him with a view of all the Constellations that ever ascend above our horizon, upon such a scale as to be easily recognized when referred to the sphere of the heavens; an advantage, which, notwithstanding the great care that has been employed in executing the maps of the northern and southern hemispheres, their very diminutive size, in a great measure, prevents their possessing.

This planisphere consists of two parts. Upon one of which (properly called the *planisphere*) the stars visible in the latitude of 51½° N. are laid down; the same considerations, however, which induced the omission of the Greek characters on the planispheres of the northern and southern hemispheres, have operated to prevent their insertion in this. The other part denominated the horizon-card, contains the horizon with the points, &c. of the compass marked upon it. The graduated right line dividing the horizon into two

PROBLEM XII.

To show at one view the time at which any given star visible in the latitude of London (not within the circle of perpetual apparition) rises or sets, or at which any star visible in that latitude culminates every day throughout the year.

Bring the given star to the eastern edge of the horizon, and against each day respectively throughout the year will stand the time at which the star rises on that day. The time of its culminating or setting throughout the year may in like manner be found by bringing the star to the meridian, or to the western verge of the horizon.

Thus, Procyon being brought to the eastern edge of the horizon, the time of its rising on any day of the year is found on the horizon-card against that day in the calendar of months on the planisphere: if the same star be brought to the meridian, the time of its culminating, and if to the western side of the horizon, the time of its setting on any day of the year may in like manner be had by inspection.

QUESTIONS FOR EXERCISE.

At what time does *Regulus* in Leo rise, culminate, and set, respectively, on the first day of the twelve calendar months?

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equal parts from north to south is the meridian, and the curve line crossing it is the east and west azimuths. Round the edge of the planisphere several concentric circles are drawn, on the innermost of which the right ascension in degrees is marked; the next contains the right ascension in time, exterior to which are the twelve calendar months divided into days, and marked accordingly. Round the edge of the horizon-card are the hours, &c.: the rest of the lines on this card need no explanation. In applying them to the machine, the planisphere, or that part upon which the constellations are delineated, is to be first put on the centre, and then the horizon-card, which last is to be secured by the silk strings to the two brass pins fixed into the frame of the Astronomicon, so as to remain perfectly steady, while the planisphere is left to turn freely upon the centre, which, in this case, becomes the pole of the Equator.

Required to show when the following stars rise, culminate, and set, on the days annexed.

Spica in Virgo on the 1st of April, 10th of May, 4th of June, and 31st of December?

Sirius on the 20th of March, 21st of June, 23d of September, and 21st of December?

PROBLEM XIII.

To represent by the planisphere the face of the heavens for any given hour of the night at any proposed time of the year.

Bring the day of the month on the planisphere to correspond with the given hour on the horizon-card, and the planisphere will present a view of the constellations corresponding with the state of the heavens at the time proposed.

Thus, on the 1st of November, at eight o'clock in the evening, the state of the heavens is nearly as follows: Lacerta is in the zenith, from which point to the north the meridian is occupied by Cepheus (between the zenith and the pole of the world), Camelopardalis, and Ursa Major; from the zenith to the south, Pegasus, Aquarius, and Piscis Australis, are on the meridian; Gloria Frederici, Andromeda, Triangula, Musca, Borealis, Taurus, and Eridanus, are on the east; and on the west we find Cygnus, Lyra, Hercules, and Ophinchus.

In the N.E. quarter of the hemisphere, we meet with Gemini, Lynx, Camelopardalis, and Cassiopeia; between the zenith, the N. and N.E., and between the zenith, the N.E. and E., are found Auriga, Perseus, the Hyades, and the Pleiades.

The S.E. quarter contains Eridanus, part of Cetus, Aries, the northern of the zodiacal Fishes, and part of Andromeda between the zenith, the E. and S.E., and the hind part of Cetus, Officina Sculptoria, the more southerly of the zodiacal Fishes, Pegasus and the River of Aquarius, are between the zenith, the S.E. and the S.

The S.W. quarter is occupied by Le Ballon, Microscopium, Sagittarius, Capricornus, Equuleus, and Delphinus, between the zenith, the S. and the S.W. And

Vulpecula et Anser, Sagitta, Aquila, Antinöus, Scutum Sobieski, Taurus Poniatowski, and Cygnus, between the zenith, the S.W. and W.

In the N.W. quarter, we find Hercules, Corona Borealis, and Draco, between the zenith, the W. and and N.W. And Böotes, Canes Venatici, the hind part of Ursa Major, the tail of Draco, and Ursa Minor, between the zenith, the N.W. and N.

QUESTIONS FOR EXERCISE.

Required the state of the heavens at London on the following days, and at the hours annexed.

January 10th, at eight in the evening, July 31st, at nine in the evening, November 6th, at three in the morning, and December 31st, at five in the morning.

PROBLEM XIV.

To find the time of the Sun's rising and setting, and consequently the length of any particular day and night at London.

Bring the Sun's place in the ecliptic for the given day to the eastern side of the horizon, and the time on the hour-circle on the horizon-card coinciding with the day of the month on the planisphere will be the time of the Sun's rising; the time of his setting is found in like manner, by bringing the Sun's place to the western edge of the horizon.

The hour of sun-setting doubled gives the length of the day, and the hour of sun-rising doubled gives the length of the night.

Thus, on the 21st of June, the Sun rises about a quarter before four, and sets about a quarter past eight,—the day is 16½, and the night 7½ hours long.

QUESTIONS FOR EXERCISE.

Required the length of the first day of each of the calendar months.

Required the length of the day on which the Sun enters Aries.

At what time does the Sun rise and set, and what is the length of the night on the 21st of December?

PROBLEM XV.

To find the beginning, end, and duration of twilight at London, on any given day.

Find the time of sunset (at which time the evening twilight begins) as in the last problem, and continuing the motion of the planisphere, till the Sun's place having passed through the part cut out of the western side of the horizon-card comes under the edge marked "EVENING TWILIGHT ENDS," take notice of the time *now* answering to the given day: the interval between the time of the Sun's setting and that last found is the duration of evening twilight.

Otherwise, bring the Sun's place for the given day under that edge of the part cut out of the eastern side of the horizon-card, marked "MORNING TWILIGHT COMMENCES," and noticing the time answering to the given day, continue the motion of the planisphere till the Sun's place comes in contact with the eastern verge of the horizon: the intervening time is the duration of morning twilight.

The time when evening twilight ends, subtracted from 12, will show the beginning of morning twilight, and the commencement of morning twilight, subtracted from 12, will give the hour at which the evening twilight ends. The morning or evening twilight doubled gives the entire twilight for the proposed day.

Thus, on the 25th of August, the Sun sets at seven o'clock, and the evening twilight ends about nine; the difference is two hours, which is the duration of evening twilight, and consequently the whole twilight on that day is four hours.

QUESTIONS FOR EXERCISE.

How long after sunset does total darkness commence on the 18th of April?

What is the total duration of twilight on the 4th of November?

At what time does morning twilight begin on the 10th of January, and what is the entire twilight for that day?

At what time does total darkness commence, and how long does it last on the 7th of August?

Show that from the 1st of June to the 13th of July, there can be no absolute night.

PROBLEM XVI.

To find the rising and setting amplitude of any star, its oblique ascension and descension, and its diurnal and nocturnal arcs.

Bring the star to the eastern edge of the horizon, then the number of degrees intercepted between the star and the eastern point of the horizon will be its rising amplitude; and the degree of the equinoctial cut by the horizon will be the oblique ascension: also observe what time in the circle of hours corresponds with the place of the star in the horizon, this time being doubled, gives the length of the nocturnal arc, or the time which the star remains below the horizon. Turn the planisphere till the given star comes to the western edge of the horizon, the setting amplitude will be the number of degrees between the star and the western point of the horizon, the oblique descension will be shewn by that degree of the equinoctial which is intersected by the horizon, and doubling the time corresponding with the point of the horizon at which the star sets will give the length of the diurnal arc.

Thus, the rising amplitude of *Bellatrix* is 10 degrees from the east towards the north, and the setting amplitude is 10 degrees from the west towards the north. The oblique ascension is about 70 degrees, and oblique descension 85 degrees. The nocturnal arc is 11, and the diurnal arc 13 hours.

QUESTIONS FOR EXERCISE.

What is the rising and setting amplitude of *Sirius*, its oblique ascension, oblique descension, and diurnal arc?

How long is Fomalhaut above our horizon, and what is its rising and setting amplitude?

PROBLEM XVII.

To find the Sun's right ascension, rising and setting amplitude, oblique ascension, oblique descension, and ascensional difference, or the time he rises before or after six, on any given day at London.

Bring the Sun's place to the meridian, and that degree of the equinoctial which is cut by the meridian is his right ascension.

His rising and setting amplitude, oblique ascension, and oblique descension, are found like those of a fixed star in the last problem.

From his right ascension subtract his oblique ascension, the remainder is the ascensional difference. Turn this into time *, then if the Sun's declination be north, the Sun rises before, and sets after six, by a space of time equal to the ascensional difference; but if his de, clination be south, he rises after, and sets before six, by an equal space of time.

Thus, on the 1st of May, the Sun's right ascension is 38½, and his oblique ascension 18½ degrees. The ascensional difference, therefore, is 20 degrees, which, converted into time, is 1 hour and 20 minutes; and as the Sun is in a northern sign, he rises 20 minutes before 5, and sets 20 minutes after 7 on that day. His rising amplitude is 25 degrees north of the east, and his setting amplitude 25 degrees north of the west.

QUESTIONS FOR EXERCISE.

Required the Sun's right ascension, rising amplitude, oblique ascension, setting amplitude, and oblique descension, on the 20th of March, and the 23d of September: what is the ascensional difference, and at what time does he rise and set?

What are the Sun's right ascension, rising amplitude, oblique ascension, setting amplitude, oblique descension, what the ascensional difference, and at what

* This is most readily done by multiplying by 4, in which case, minutes of longitude produce seconds, and degrees of longitude produce minutes of time.

time does he rise and set on the 21st of June, and the 21st of December?

PROBLEM XVIII.

*To find the time of the year at which any star will rise or set cosmically *; that is, when it rises or sets at sunrise, in the latitude of London.*

Bring the given star to the eastern edge of the horizon, and observe what sign and degree of the ecliptic are intersected by the horizon; the day of the month answering to that sign and degree will be that in which the proposed star rises with the Sun. Turn the planisphere till the star comes to the western edge of the horizon, and observe what degree of the ecliptic is then rising above the eastern verge of the horizon; the day of the month which coincides with it is that on which the given star sets when the Sun rises.

Thus, *Procyon* rises cosmically on the 29th of July, and sets cosmically on the 21st of December.

QUESTIONS FOR EXERCISE.

When does *Aldebaran* rise and set cosmically?

When do the *Pleiades* rise with the Sun, and when do they set at sunrising?

At what time of the year does *Sirius* rise and set cosmically?

PROBLEM XIX.

To find the time of the year when any star rises or sets acronycally, that is, when it rises or sets at the time of sunsetting at London.

Bring the star to the eastern edge of the horizon, and observe what degree of the ecliptic is intersected by the western edge; the day of the month answering to that degree is the day on which the given star rises at sunset, and consequently when it begins to be *visible in the evening.* To find on what day the star sets acronycally, bring the said star to the western edge of the horizon; then the day of the month

* See Lecture VII. p. 117.

answering to the degree of the ecliptic which sets with it is that on which the given star sets with the Sun, and consequently *ceases to appear in the evening.*

Thus, the Pleiades rise acronycally on the 5th of November, and set acronycally on the 23d of May.

QUESTIONS FOR EXERCISE.

When does *Ras Alhague* in Ophiuchus, rise and set acronycally?

During what months of the year are the following stars visible in the evening: *Deneb Algedi* in Capricornus, *Denebola* in Leo, and *Betelgeux* in Orion?

PROBLEM XX.

To find when any given star rises or sets heliacally, that is, when a star having been immersed in the Sun's beams emerges out of them, and becomes visible at the eastern edge of the horizon just before sun-rising, or when it is so near the Sun's rays at the time of its setting as to appear for the last time in the evening, before it is altogether lost.

It has been observed*, that "stars of the first magnitude may be seen rising and setting when the Sun is 12° below the horizon; stars of the second magnitude, when the depression of the Sun is 13°, and so on, one additional degree of depression of the Sun being required for every decrease of magnitude in the stars."

In order, therefore, that the heliacal rising and setting of the stars in the latitude of London may be readily determined by this planisphere, portions extending from 12 to 18 degrees beyond the horizon have been cut out of the horizon-card, and consequently leaving edges which become the boundaries of these spaces. To perform this problem, therefore, bring the given star to the eastern verge of the horizon, and if the star be of the 1st magnitude, the degree of the ecliptic intersected by that edge of the

* See Lecture VII. p. 118.

card which forms the boundary of the open space nearest the horizon being referred to the calendar of months will show the day of the month when the star rises heliacally. If the star be of the 2d magnitude, take the point of the ecliptic one degree distant from this edge, or 13 degrees from the edge of the horizon; if the star be of the 3d magnitude, take a point of the ecliptic two degrees distant from this edge, or 14 degrees from the edge of the horizon, and so on, according to the magnitude of the star, then the day answering to that degree of the ecliptic will be the day sought, or that on which the given star rises heliacally. Bringing the star to the western verge of the horizon, and performing a similar operation, will give the day on which it sets heliacally.

Thus, Procyon rises heliacally on the 15th of August, and sets heliacally on the 25th of May.

QUESTIONS FOR EXERCISE.

At what time of the year does *Arcturus* rise heliacally at London, and on what day does it set heliacally at the same place?

On what days do the following stars rise and set heliacally: *Sirius*, *Deneb Algedi* in Capricornus, and *Menkar* in Cetus.

THE END.

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